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Hong et al.

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(54) **TOUCH DEVICE AND DISPLAY DEVICE INCLUDING THE SAME**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 335 days.

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(30) **Foreign Application Priority Data**

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G06F 3/043 (2006.01)
G06F 3/0488 (2013.01)
(Continued)

(52) **U.S. Cl.**
CPC ***G06F 3/0436*** (2013.01); ***G06F 1/1626*** (2013.01); ***G06F 1/1643*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC G06F 3/0436; G06F 1/1626; G06F 3/0485; G06F 3/04845; G06F 3/0416;
(Continued)

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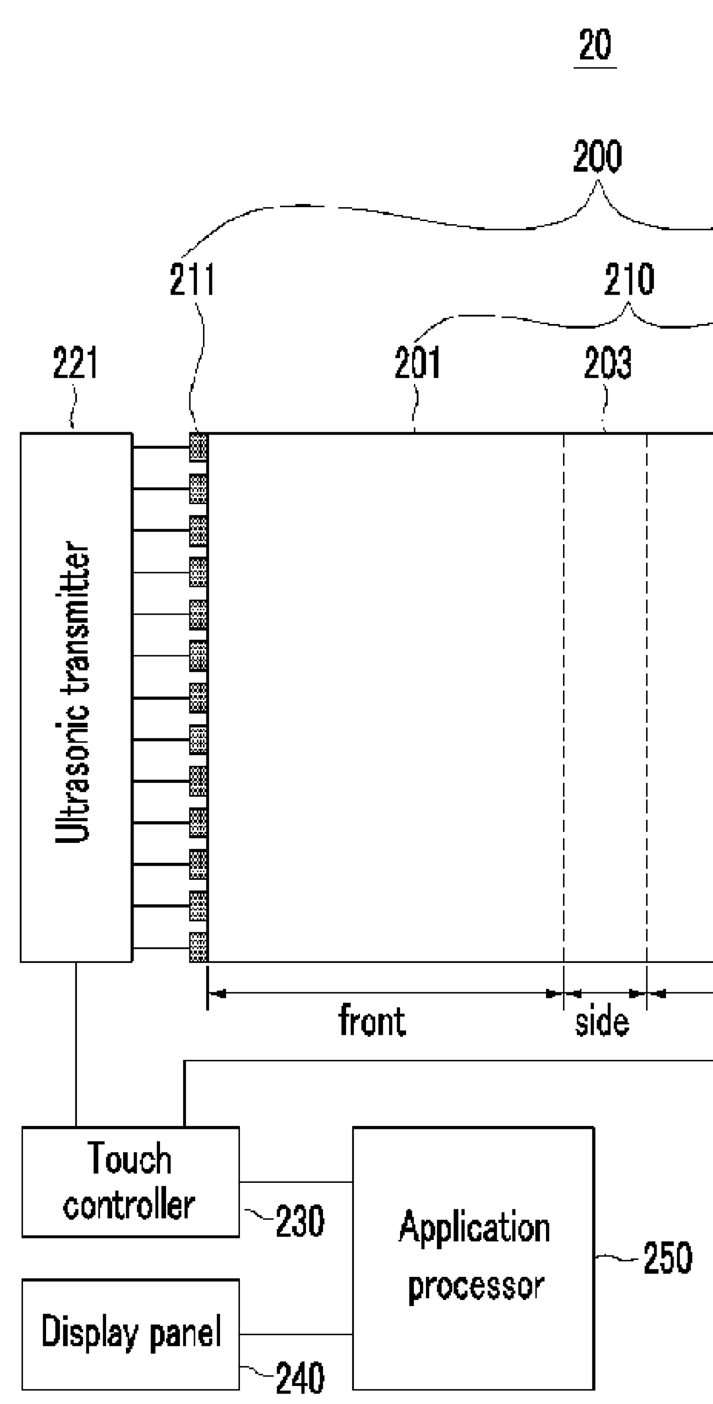
Primary Examiner — Patrick Edouard
Assistant Examiner — Joseph Fox
(74) *Attorney, Agent, or Firm* — Innovation Counsel LLP

(57) **ABSTRACT**

A touch device and a display device including the same are provided. The touch device includes: a first substrate; a second substrate facing the first substrate, and disposed to be spaced apart from the first substrate by a predetermined interval; a third substrate connecting first end portions of the first and second substrates to each other, and propagating an ultrasonic signal propagated along the first substrate to the second substrate; a plurality of first ultrasonic transducers connected to second portions facing the first end portions in the first substrate, and propagating an ultrasonic signal to the first substrate; and a plurality of second ultrasonic transducers connected to the second portions facing the first end portions in the second substrate, and receiving an ultrasonic signal propagated along the second substrate, wherein a touch point may be detected based on signal intensity variations of ultrasonic signals received by the second ultrasonic transducers.

21 Claims, 33 Drawing Sheets



(51) **Int. Cl.**

G06F 1/16	(2006.01)
G06F 3/041	(2006.01)
G06F 3/0484	(2013.01)
G06F 3/0485	(2013.01)

(52) **U.S. Cl.**
CPC ***G06F 3/0416*** (2013.01); ***G06F 3/0485*** (2013.01); ***G06F 3/04845*** (2013.01); ***G06F 3/04883*** (2013.01); ***G06F 3/04886*** (2013.01); *G06F 3/043* (2013.01); *G06F 2203/04102* (2013.01); *G06F 2203/04104* (2013.01); *G06F 2203/04808* (2013.01)

(58) **Field of Classification Search**
CPC G06F 3/04886; G06F 1/1643; G06F 3/04883; G06F 3/043; G06F 2203/04102; G06F 2203/04808; G06F 2203/04104; G06F 3/0433
See application file for complete search history.

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FIG. 1A

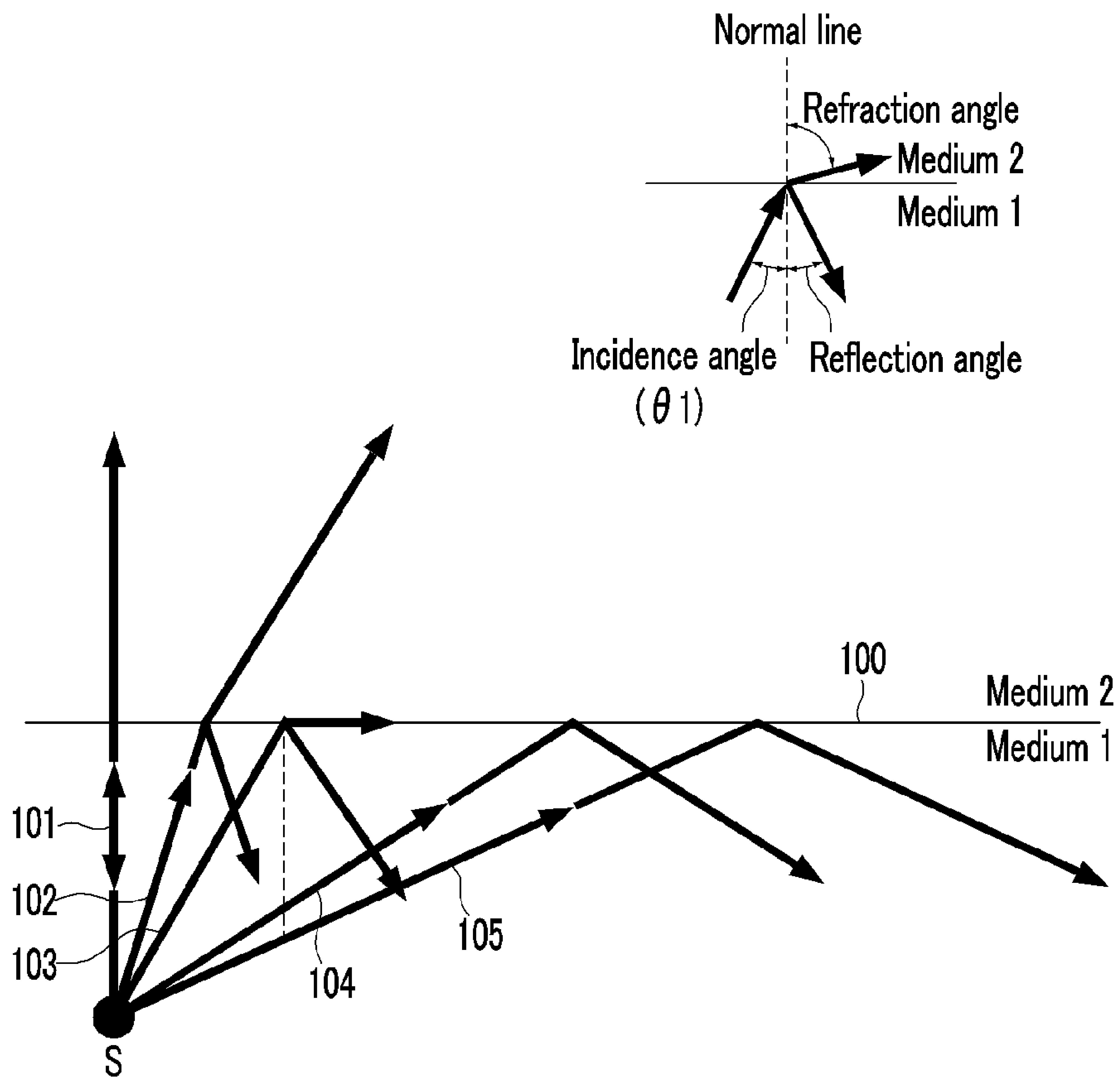

Normal line
Refraction angle
Medium 2
Medium 1
Incidence angle
(θ1)
Reflection angle
100
Medium 2
Medium 1
101
102
103
104
105
S

FIG. 1B

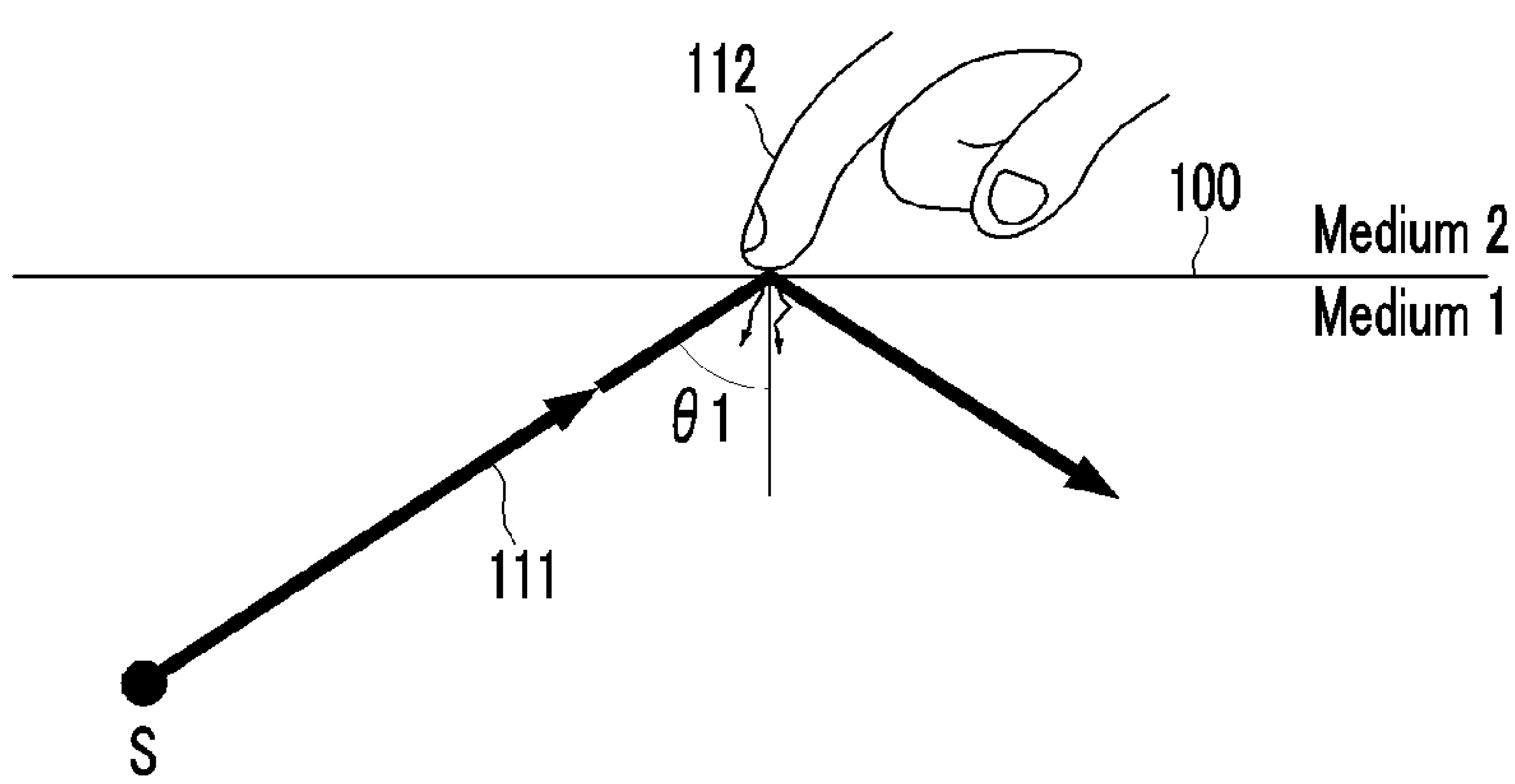


FIG. 2

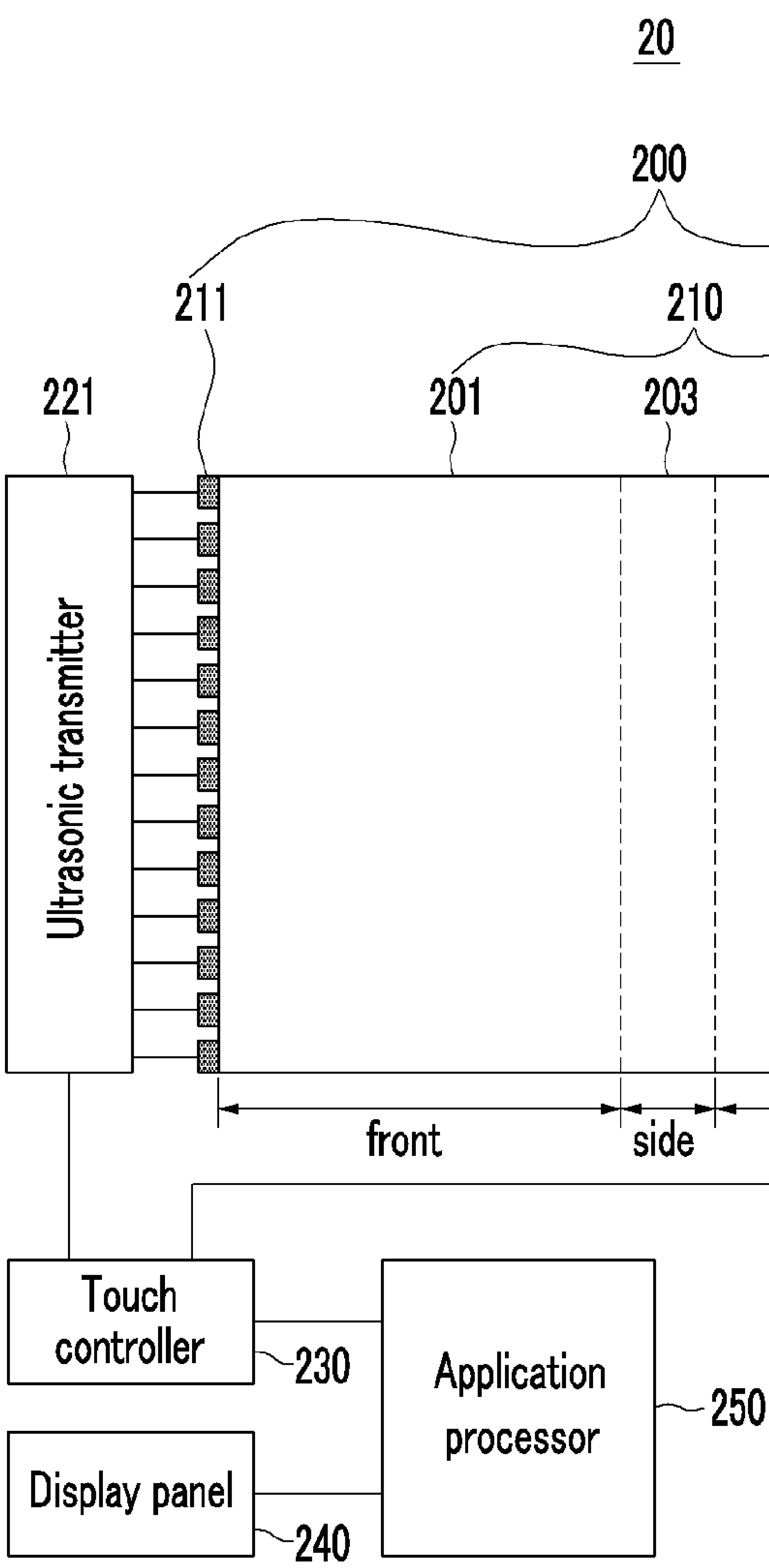

20
200
211
210
212
221
201
203
202
222
Ultrasonic transmitter
Ultrasonic receiver
front
side
back
Touch controller
230
Application processor
250
Display panel
240

FIG. 3A

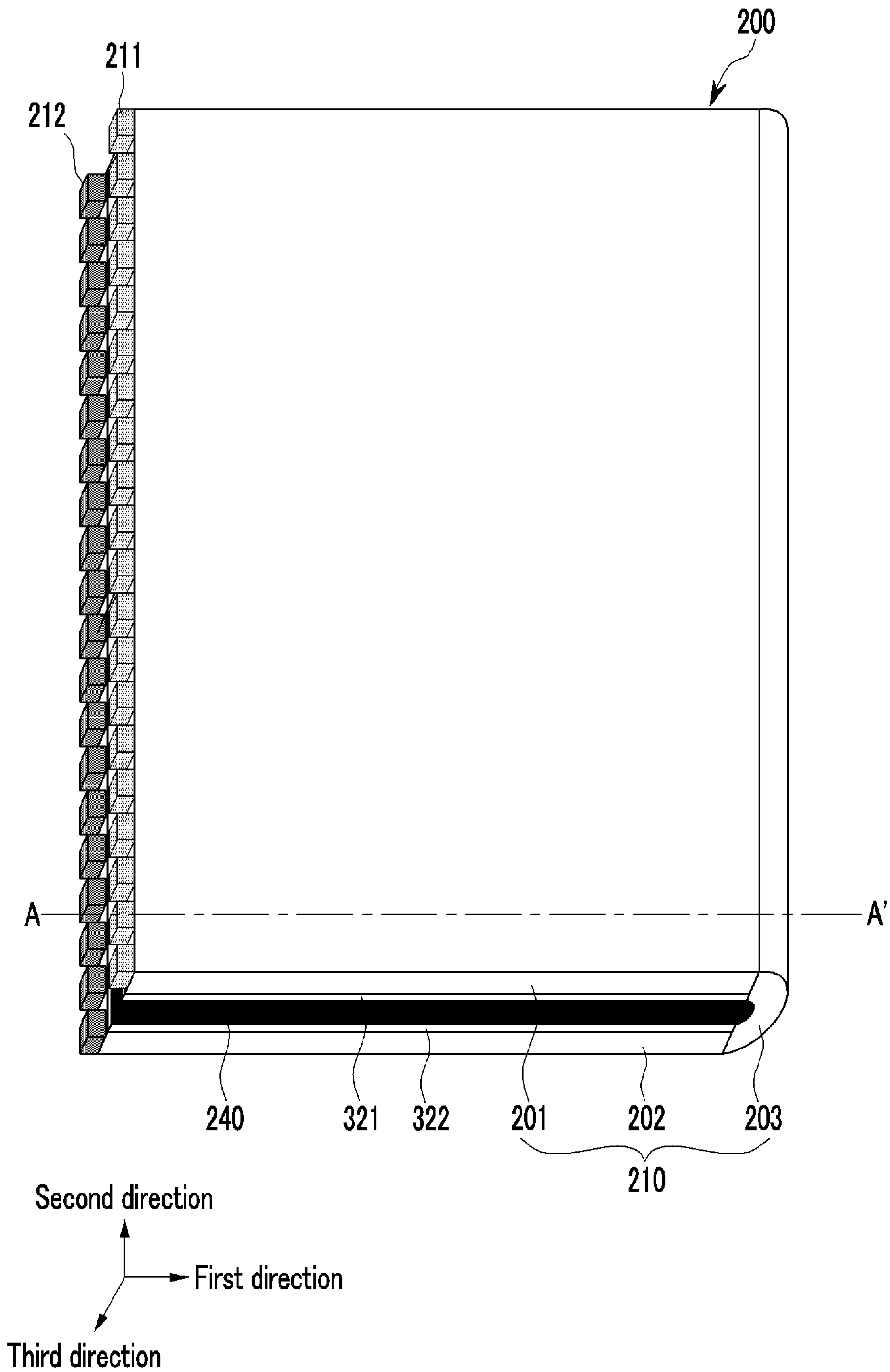

200
211
212
A
A'
240
321
322
201
202
203
210
Second direction
First direction
Third direction

FIG. 3B

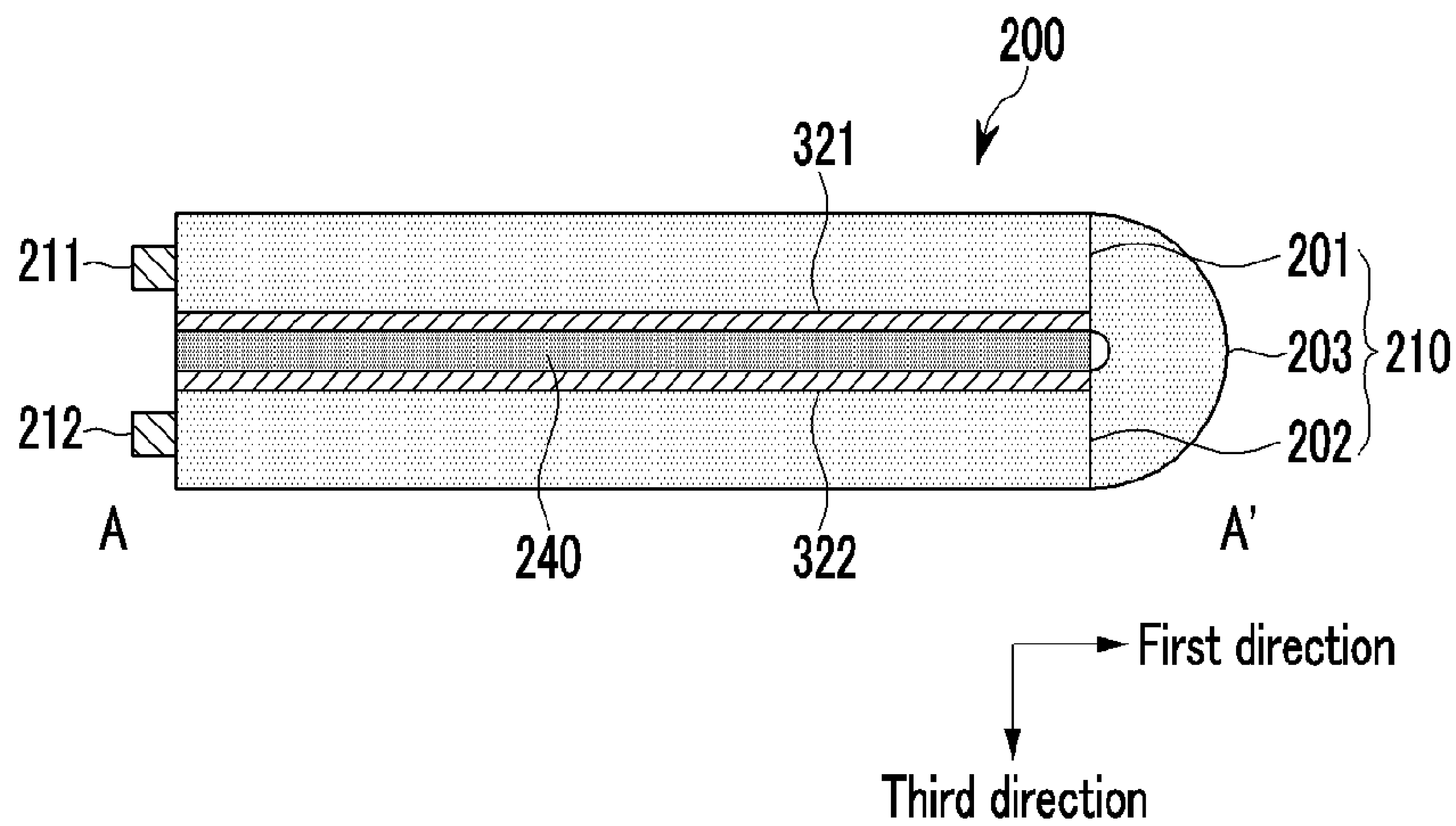

200
321
211
201
203
210
212
202
A
240
322
A'
First direction
Third direction

FIG. 3C

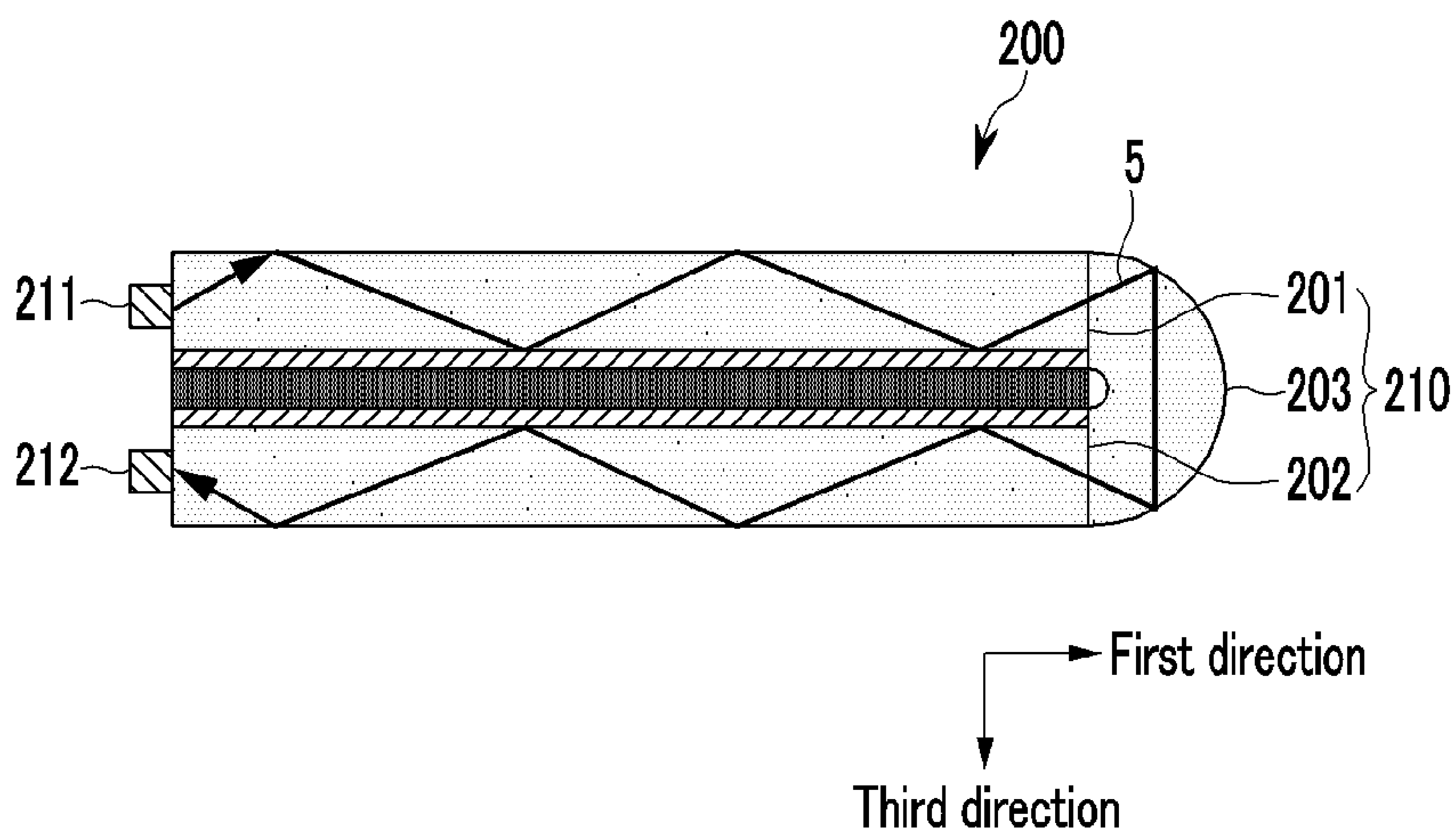

200
5
211
212
201
203
202
210
First direction
Third direction

FIG. 4

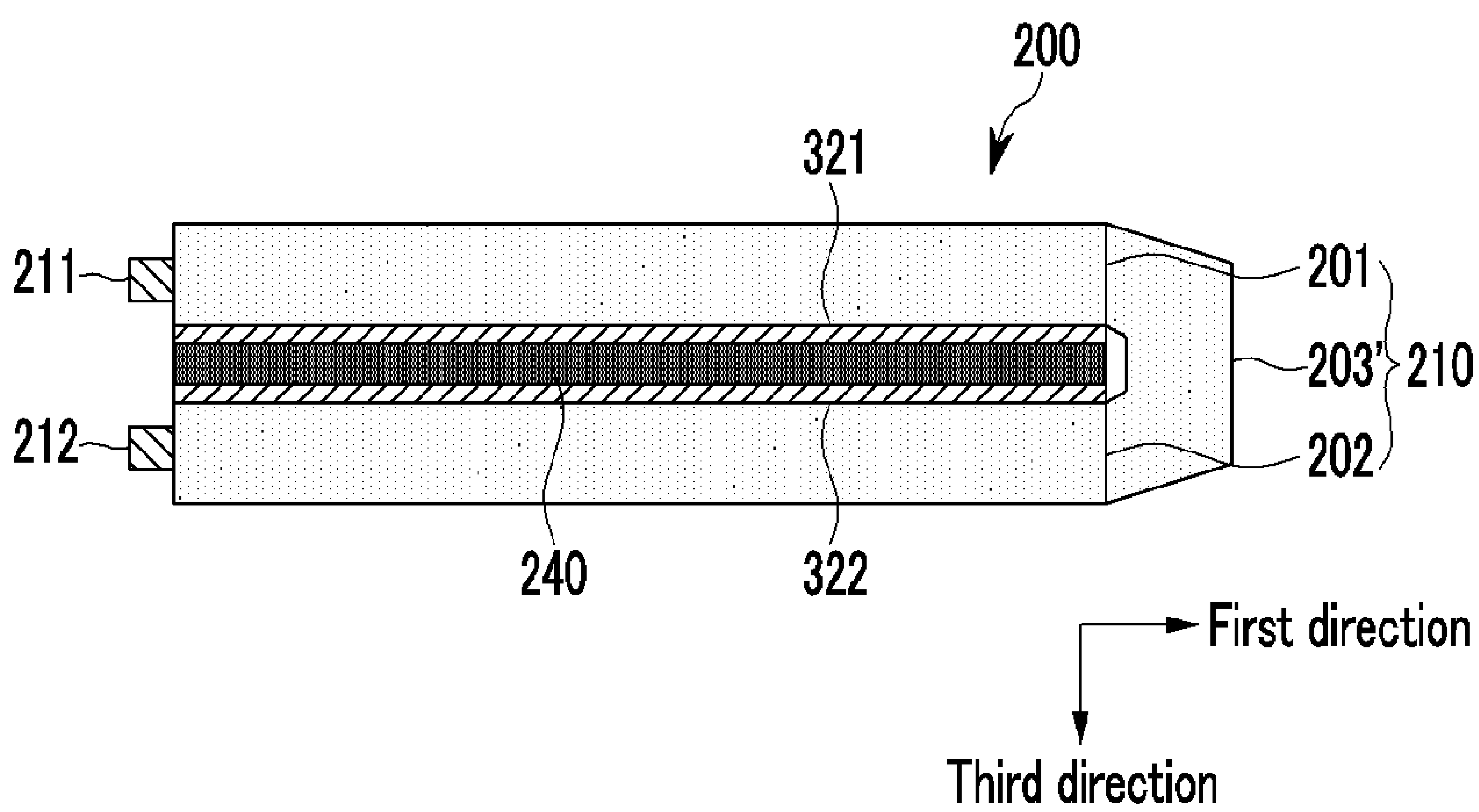

200
321
211
212
201
203'
210
202
240
322
First direction
Third direction

FIG. 5A

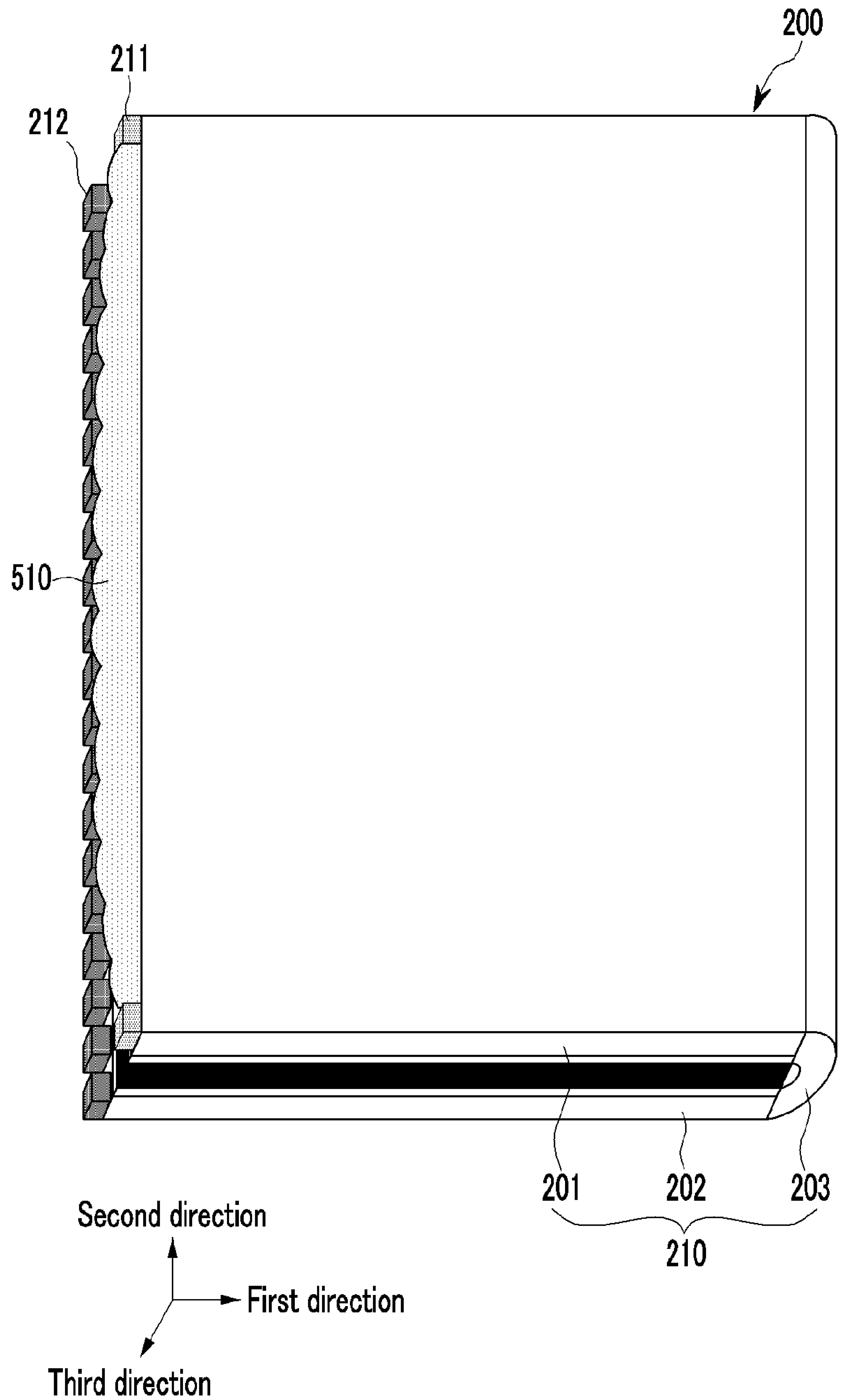

200
211
212
510
201
202
203
210
Second direction
First direction
Third direction

FIG. 5B

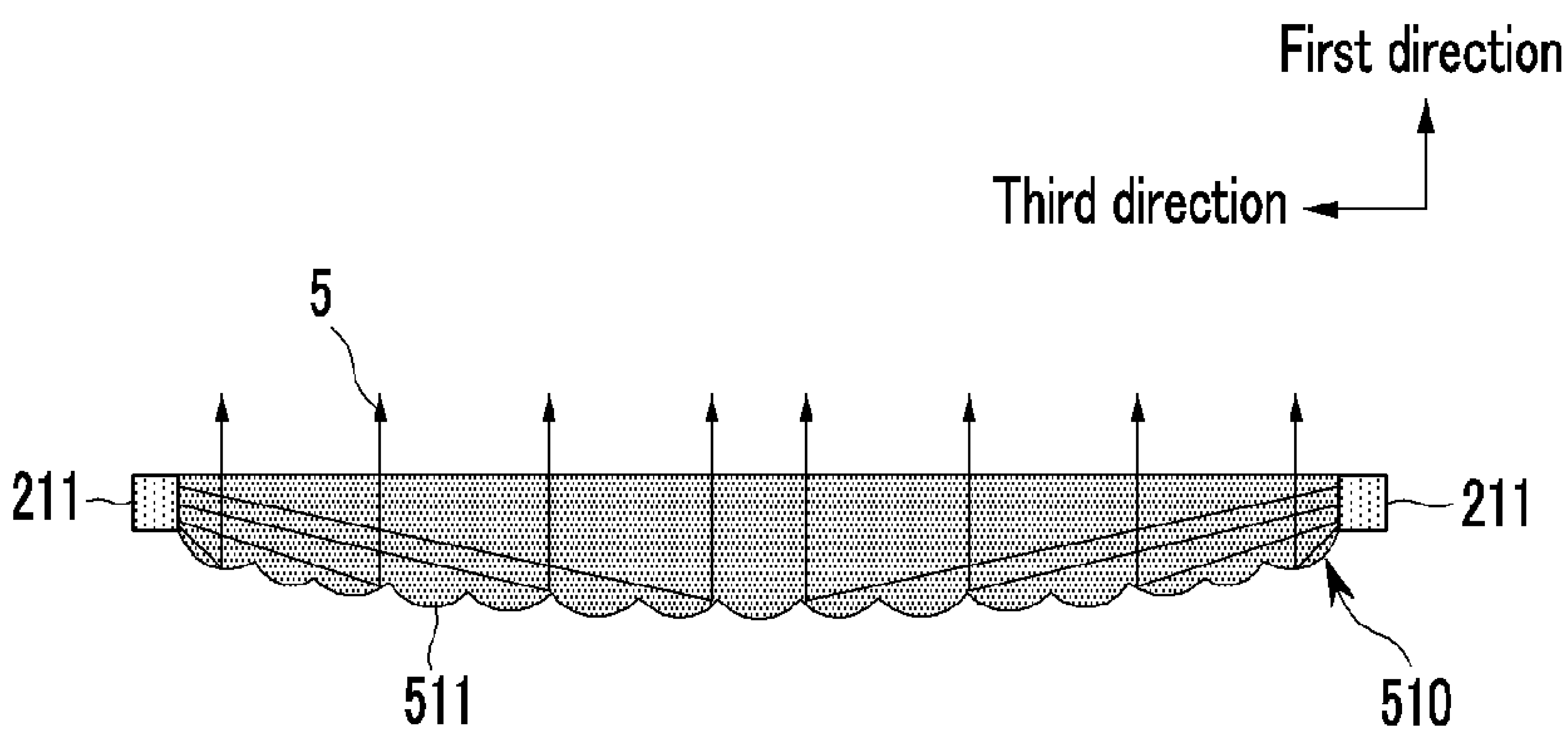


FIG. 5C

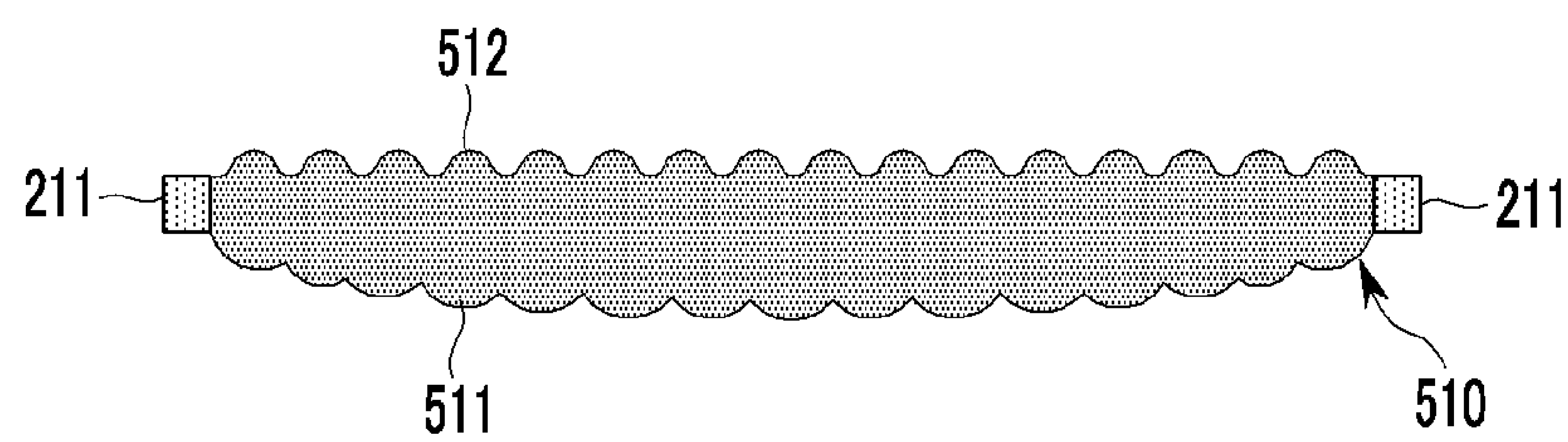


FIG. 5D

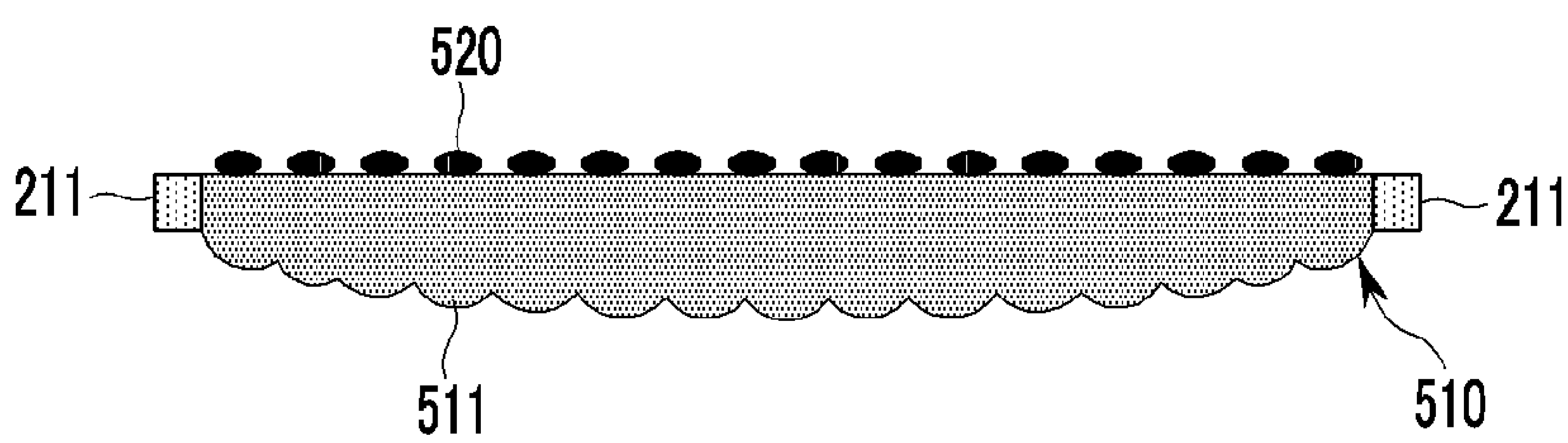
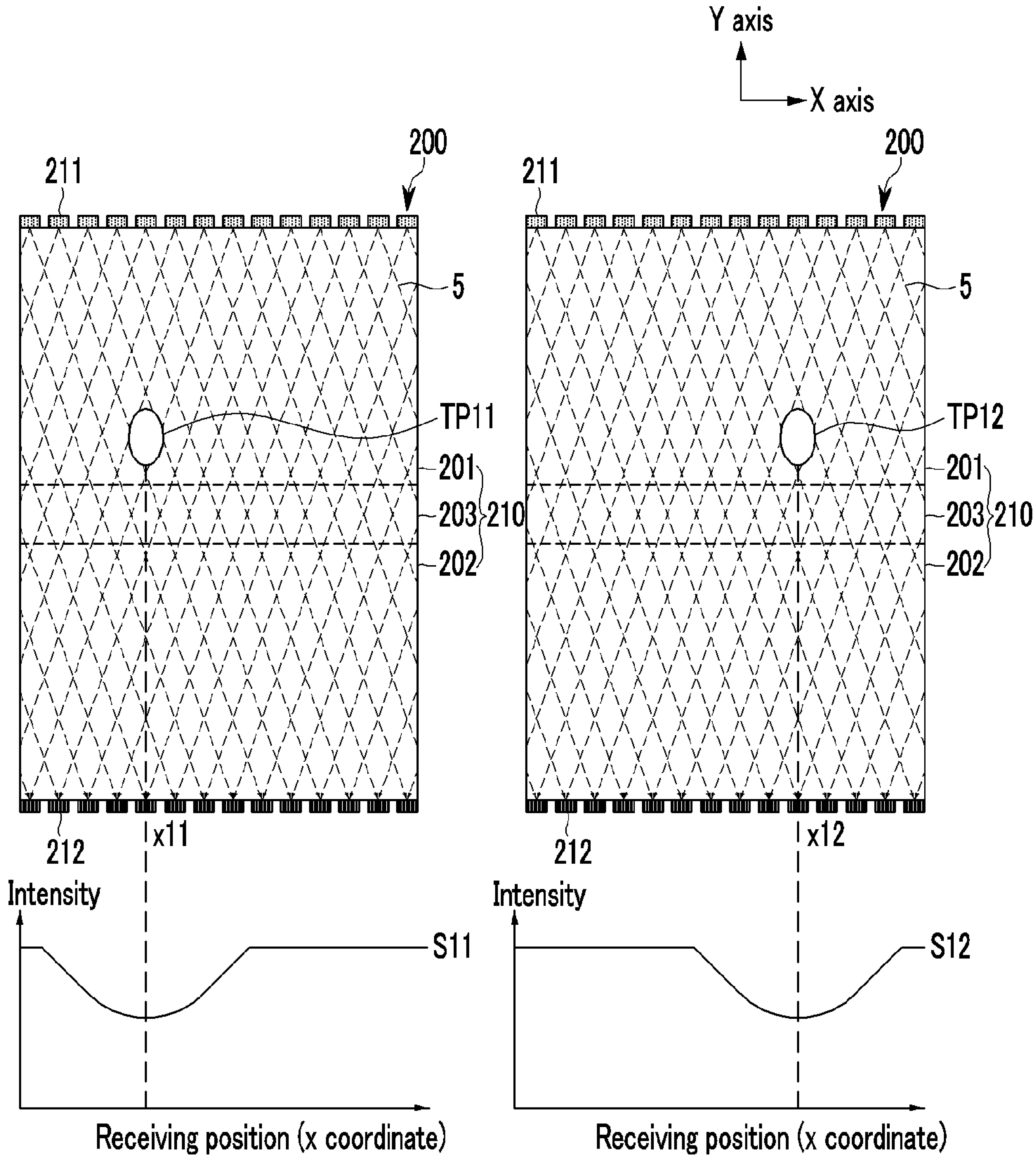


FIG. 6A



Y axis
X axis
200
211
5
TP11
201
203
210
202
212
x11
Intensity
S11
Receiving position (x coordinate)
200
211
5
TP12
201
203
210
202
212
x12
Intensity
S12
Receiving position (x coordinate)

FIG. 6B

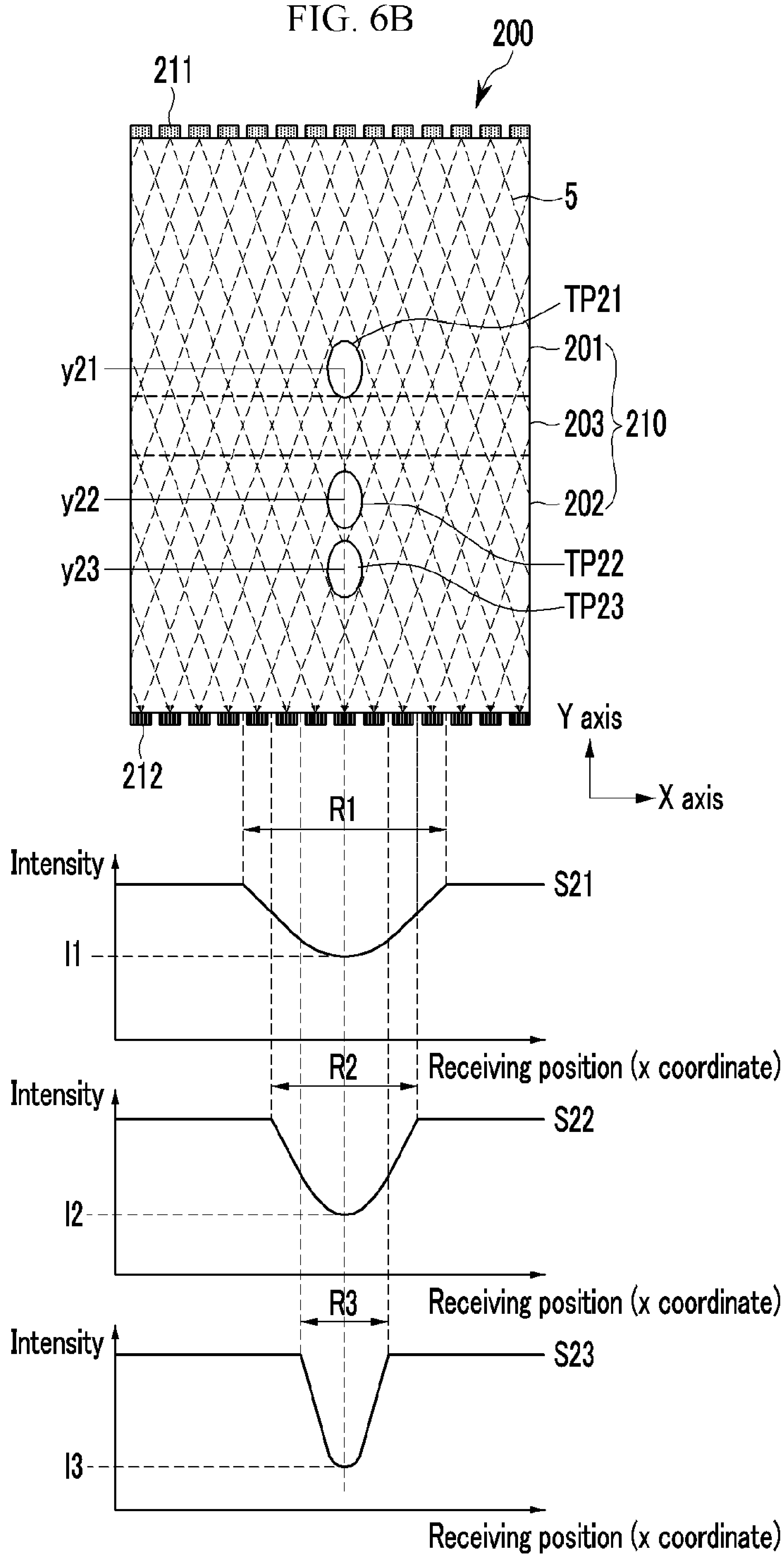

200
211
5
TP21
y21
201
203
210
202
y22
y23
TP22
TP23
Y axis
X axis
212
R1
Intensity
S21
I1
Receiving position (x coordinate)
R2
Intensity
S22
I2
Receiving position (x coordinate)
R3
Intensity
S23
I3
Receiving position (x coordinate)

FIG. 6C

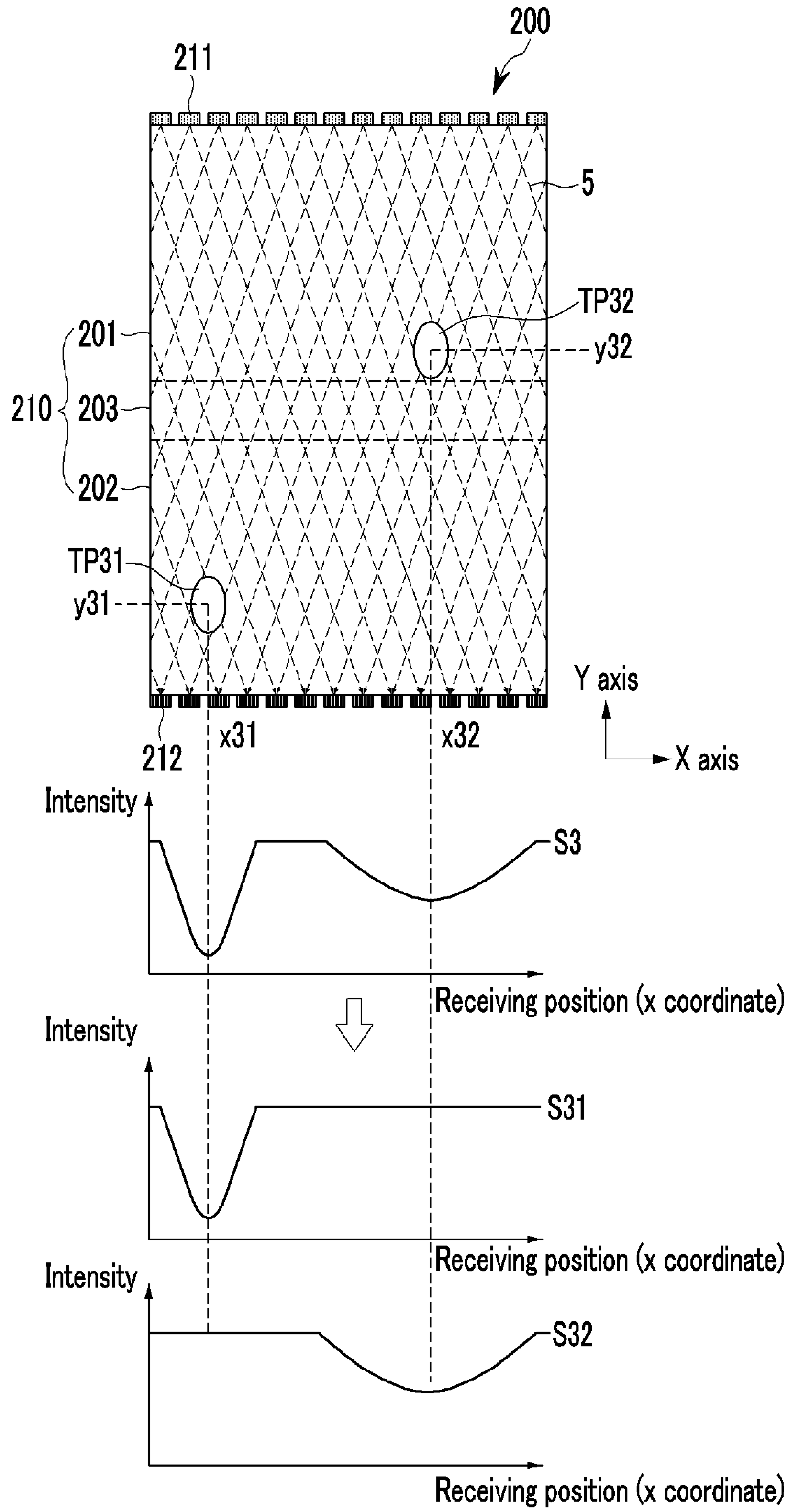

200
211
5
TP32
201
y32
210
203
202
TP31
y31
Y axis
212
x31
x32
X axis
Intensity
S3
Receiving position (x coordinate)
Intensity
S31
Receiving position (x coordinate)
Intensity
S32
Receiving position (x coordinate)

FIG. 6D

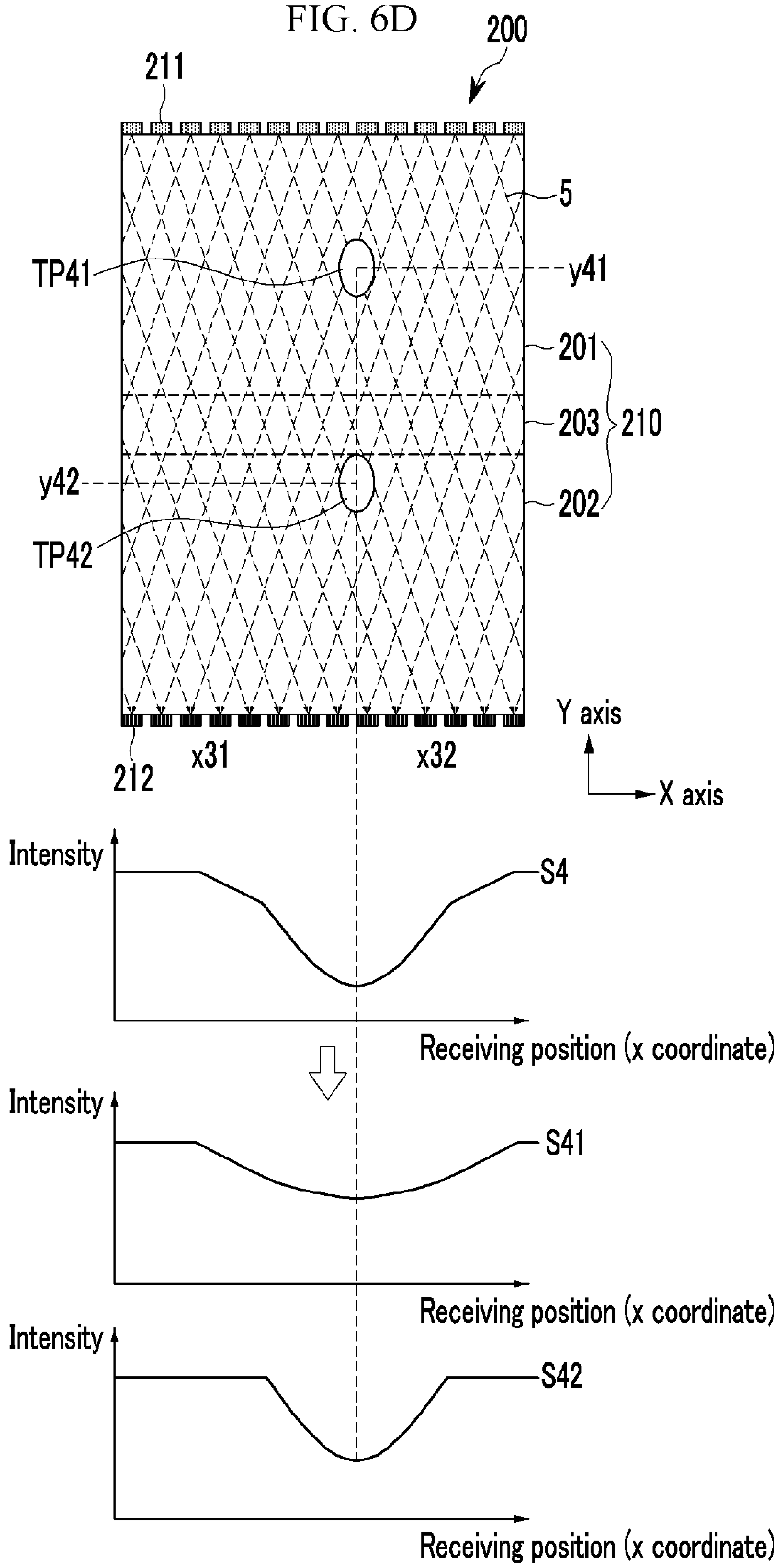

200
211
5
TP41
y41
201
203
210
y42
202
TP42
Y axis
X axis
212
x31
x32
Intensity
S4
Receiving position (x coordinate)
Intensity
S41
Receiving position (x coordinate)
Intensity
S42
Receiving position (x coordinate)

FIG. 7

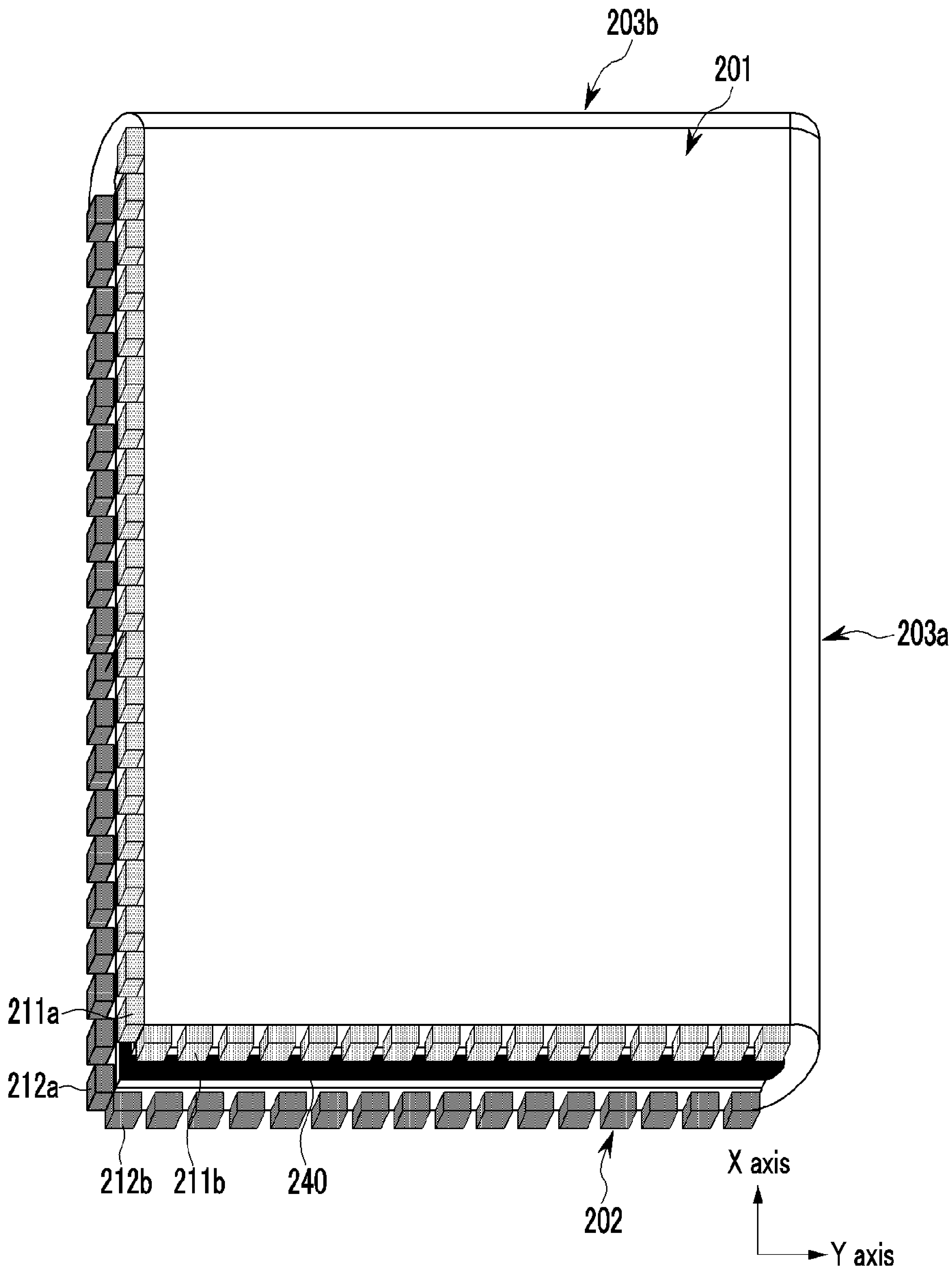


FIG. 8

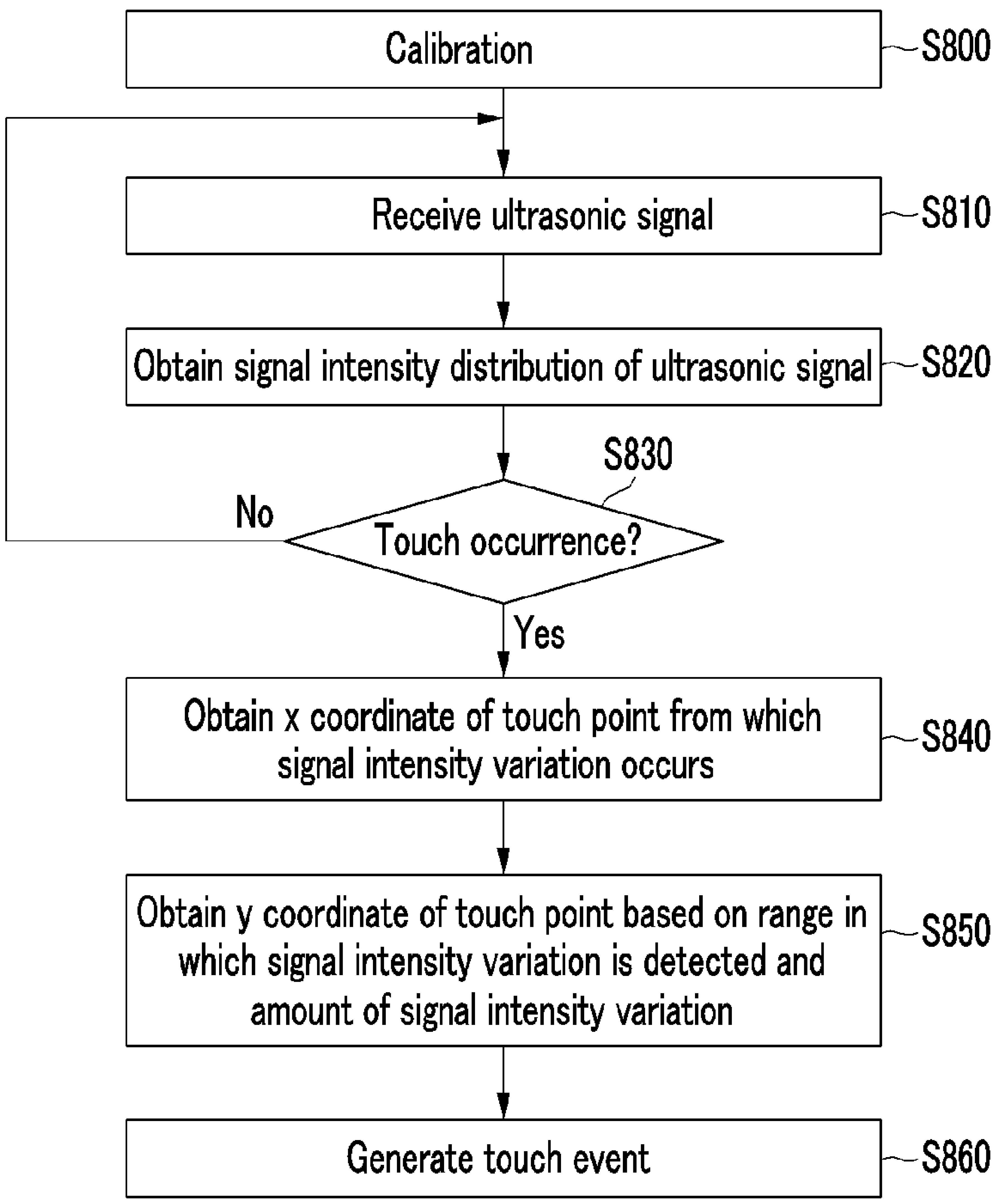

Calibration
S800
Receive ultrasonic signal
S810
Obtain signal intensity distribution of ultrasonic signal
S820
S830
No
Touch occurrence?
Yes
Obtain x coordinate of touch point from which signal intensity variation occurs
S840
Obtain y coordinate of touch point based on range in which signal intensity variation is detected and amount of signal intensity variation
S850
Generate touch event
S860

FIG. 9

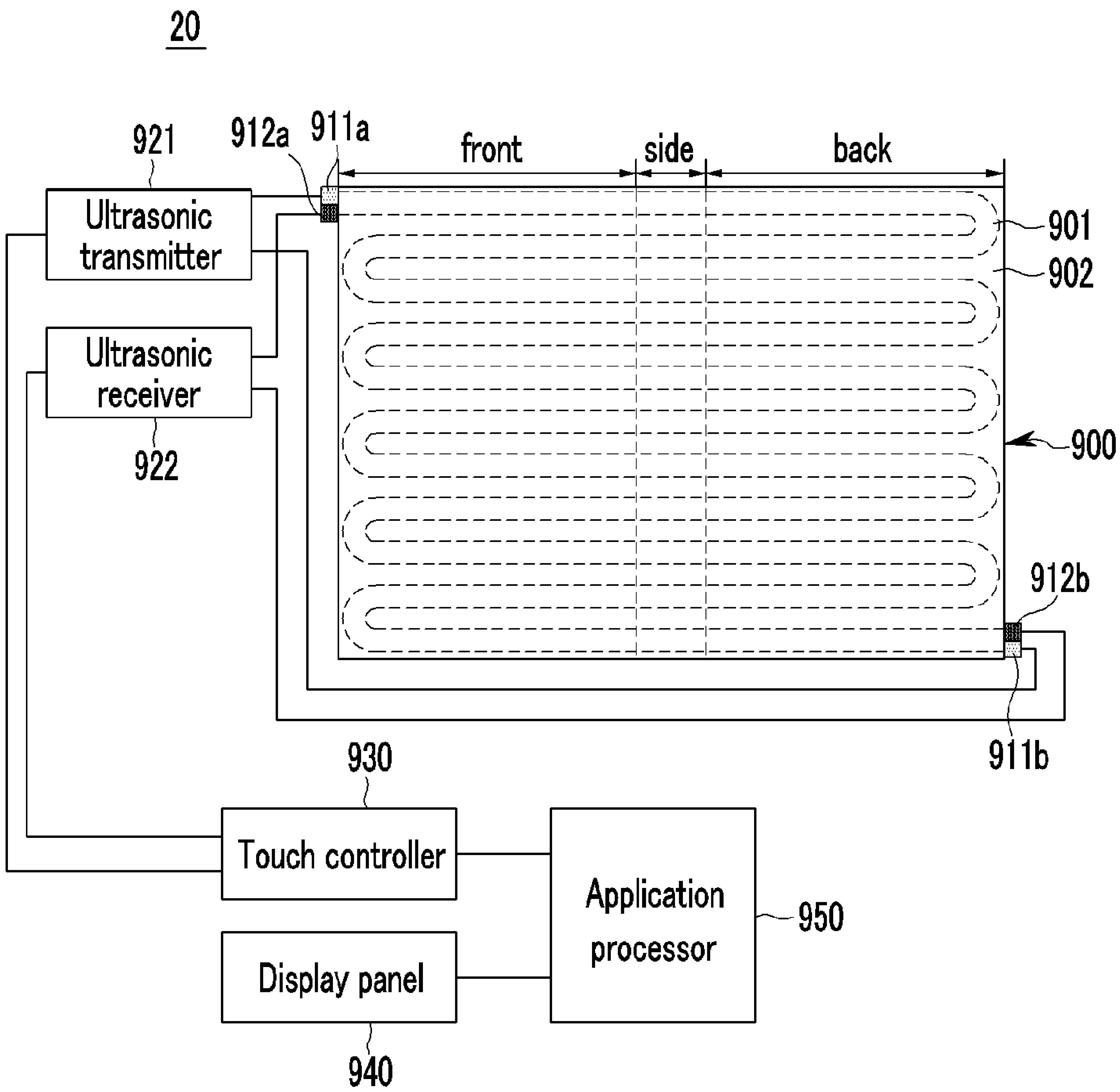

20
921
912a
911a
front
side
back
Ultrasonic transmitter
901
902
Ultrasonic receiver
922
900
912b
911b
930
Touch controller
Application processor
950
Display panel
940

FIG. 10A

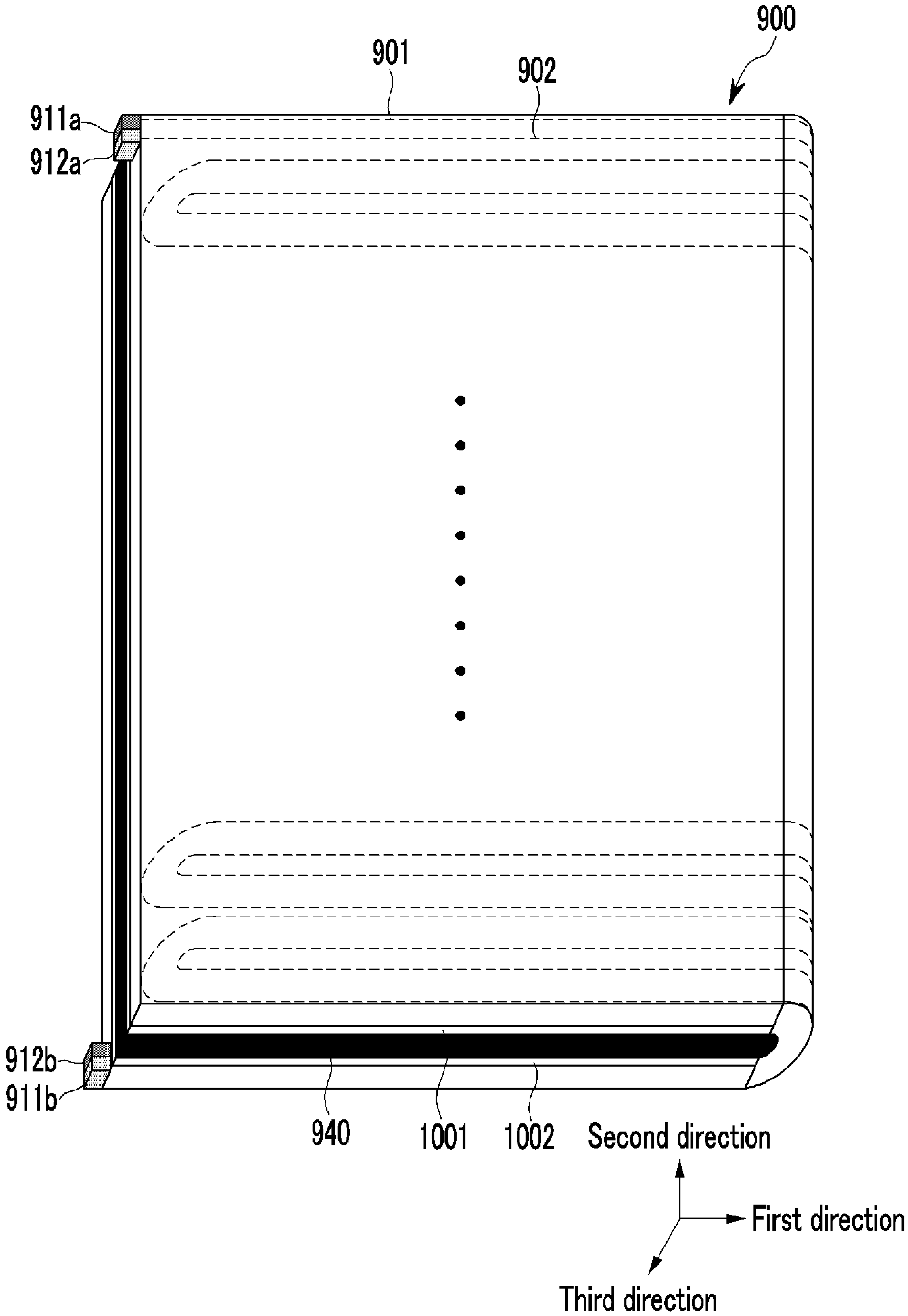

900
901
902
911a
912a
912b
911b
940
1001
1002
Second direction
First direction
Third direction

FIG. 10B

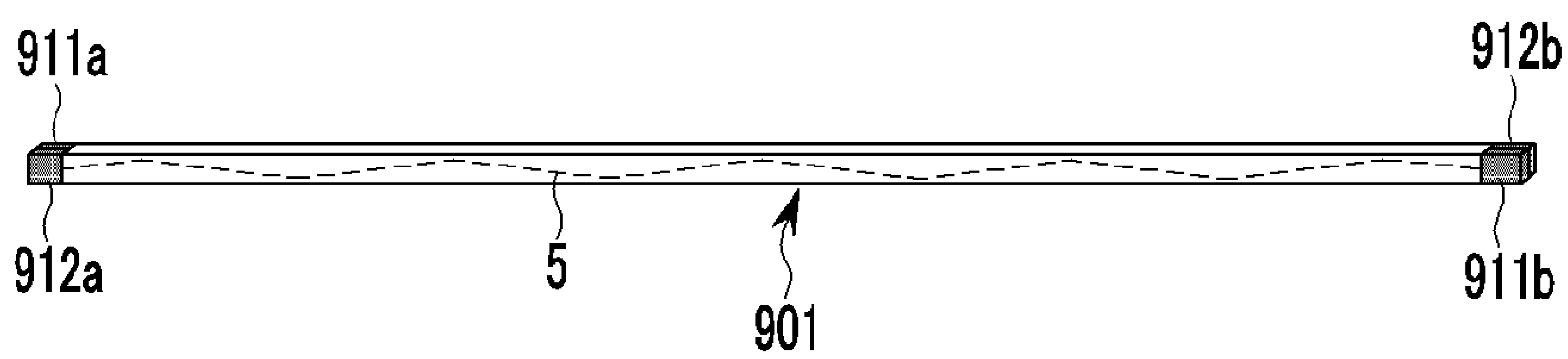


FIG. 10C

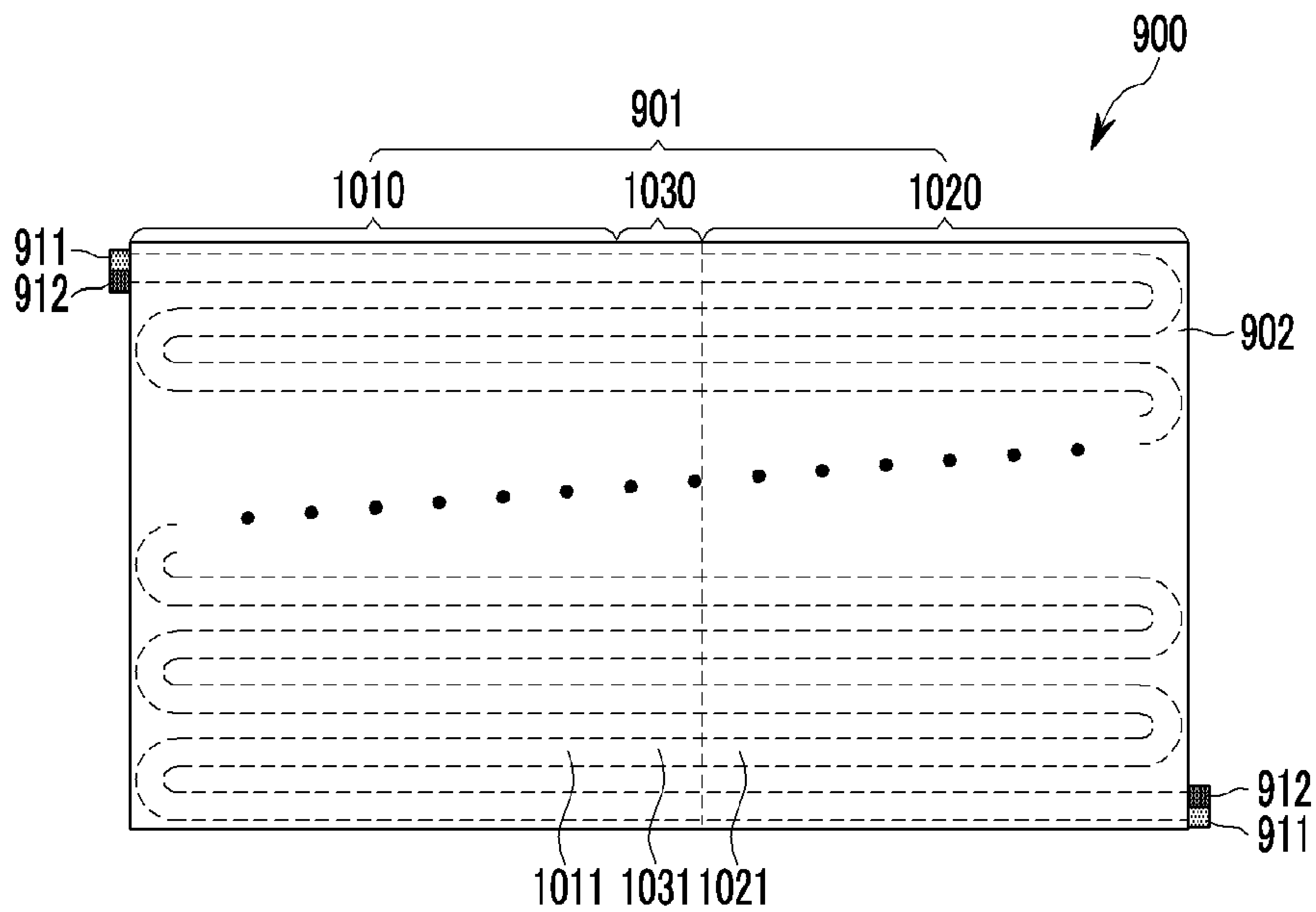


FIG. 11A

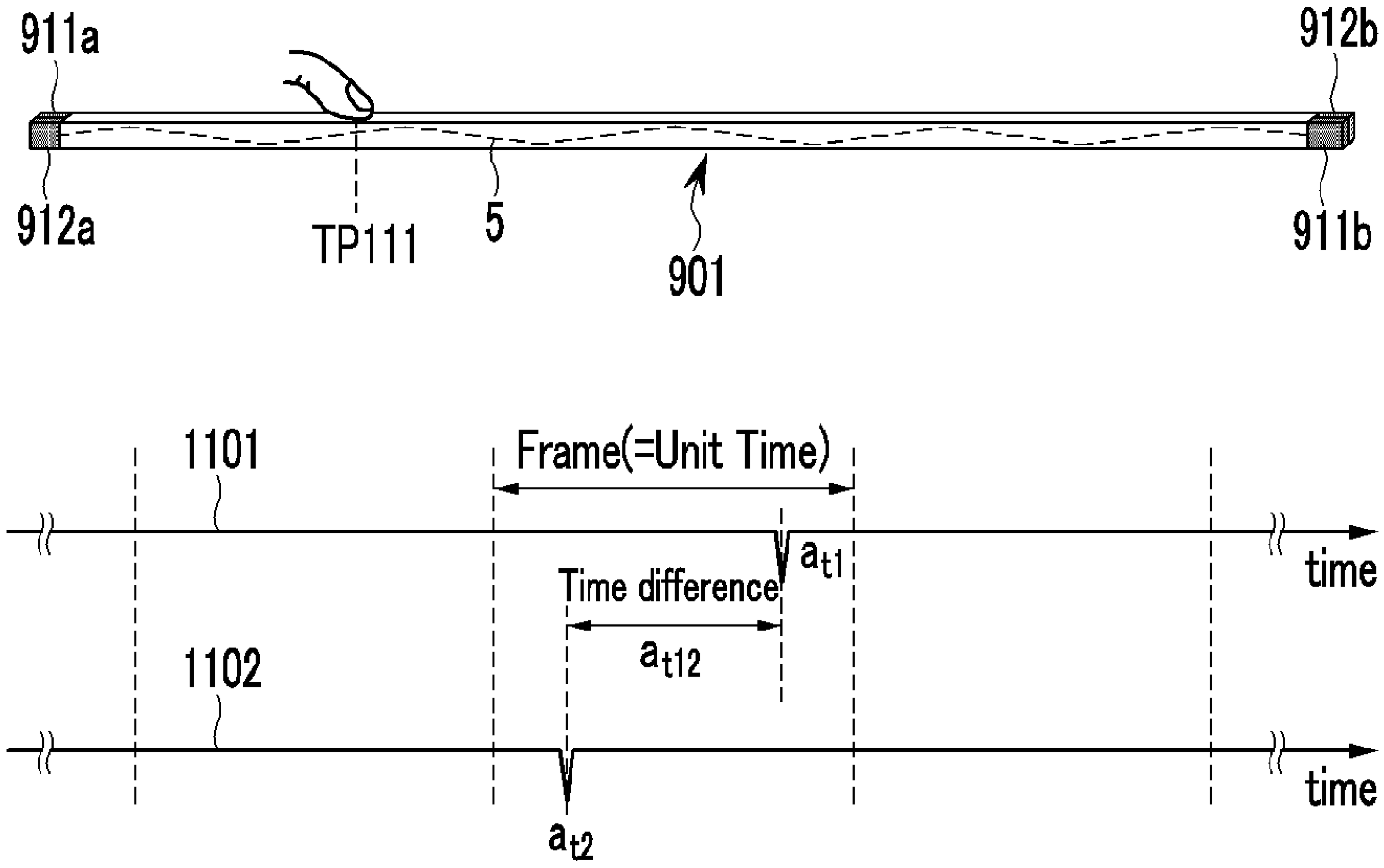

911a
912b
912a
TP111
5
901
911b
1101
Frame(=Unit Time)
a_{t1}
time
Time difference
a_{t12}
1102
time
a_{t2}

FIG. 11B

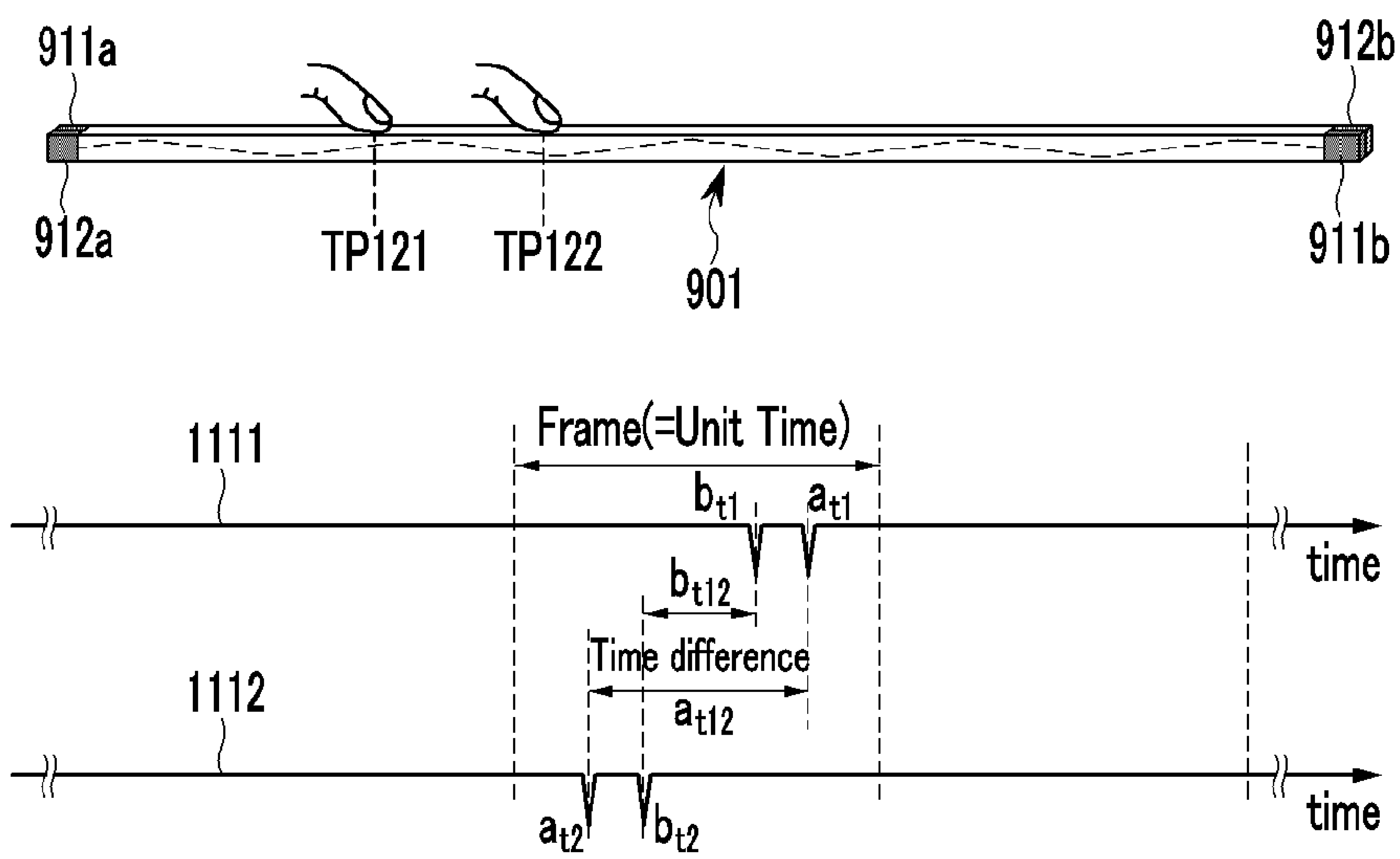

911a
912b
912a
TP121
TP122
901
911b
Frame(=Unit Time)
1111
b_{t1}
a_{t1}
time
b_{t12}
Time difference
a_{t12}
1112
a_{t2}
b_{t2}
time

FIG. 11C

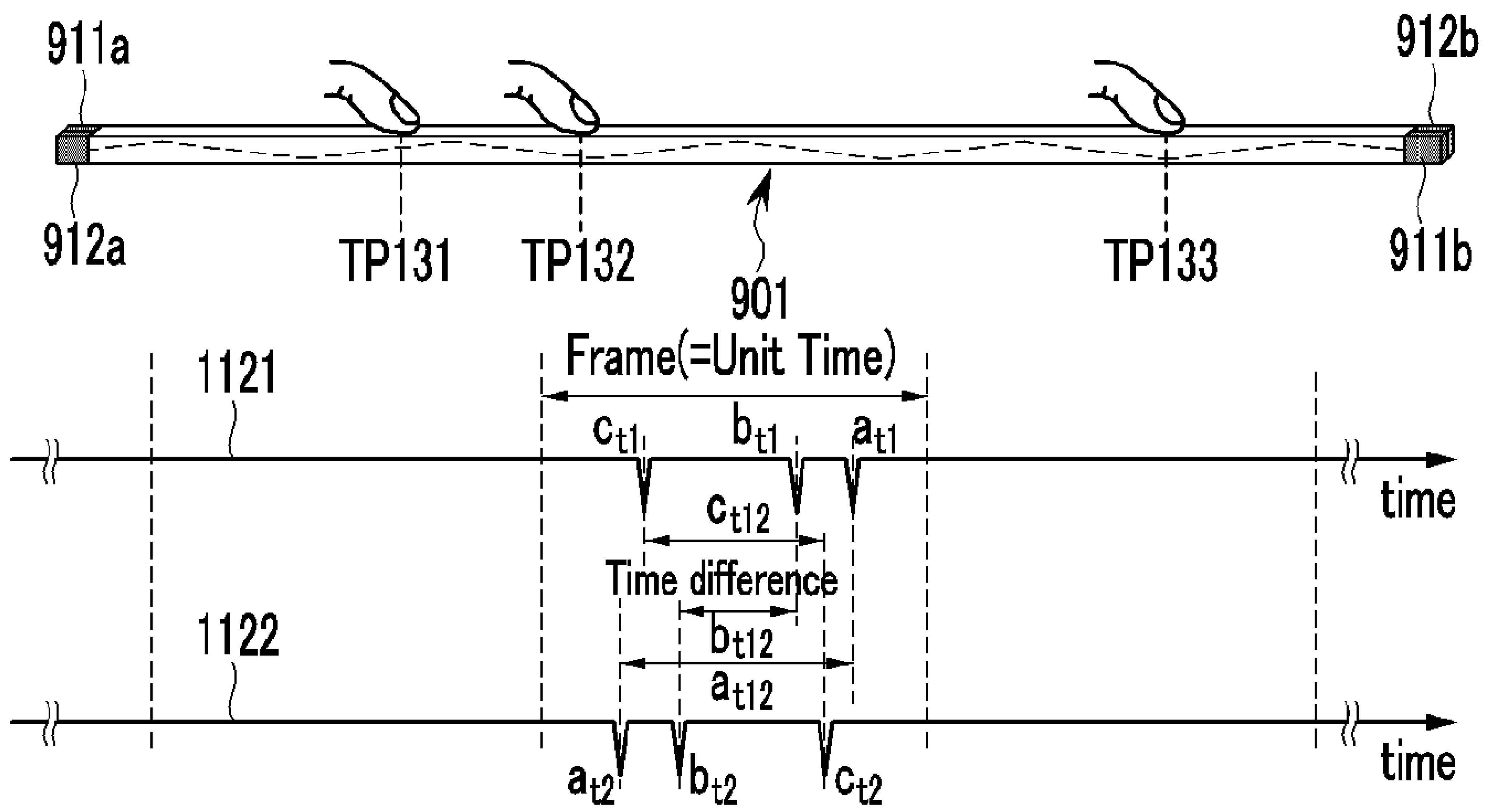

911a
912b
912a
TP131
TP132
901
TP133
911b
Frame(=Unit Time)
1121
c_{t1}
b_{t1}
a_{t1}
time
c_{t12}
Time difference
b_{t12}
1122
a_{t12}
time
a_{t2}
b_{t2}
c_{t2}

FIG. 12

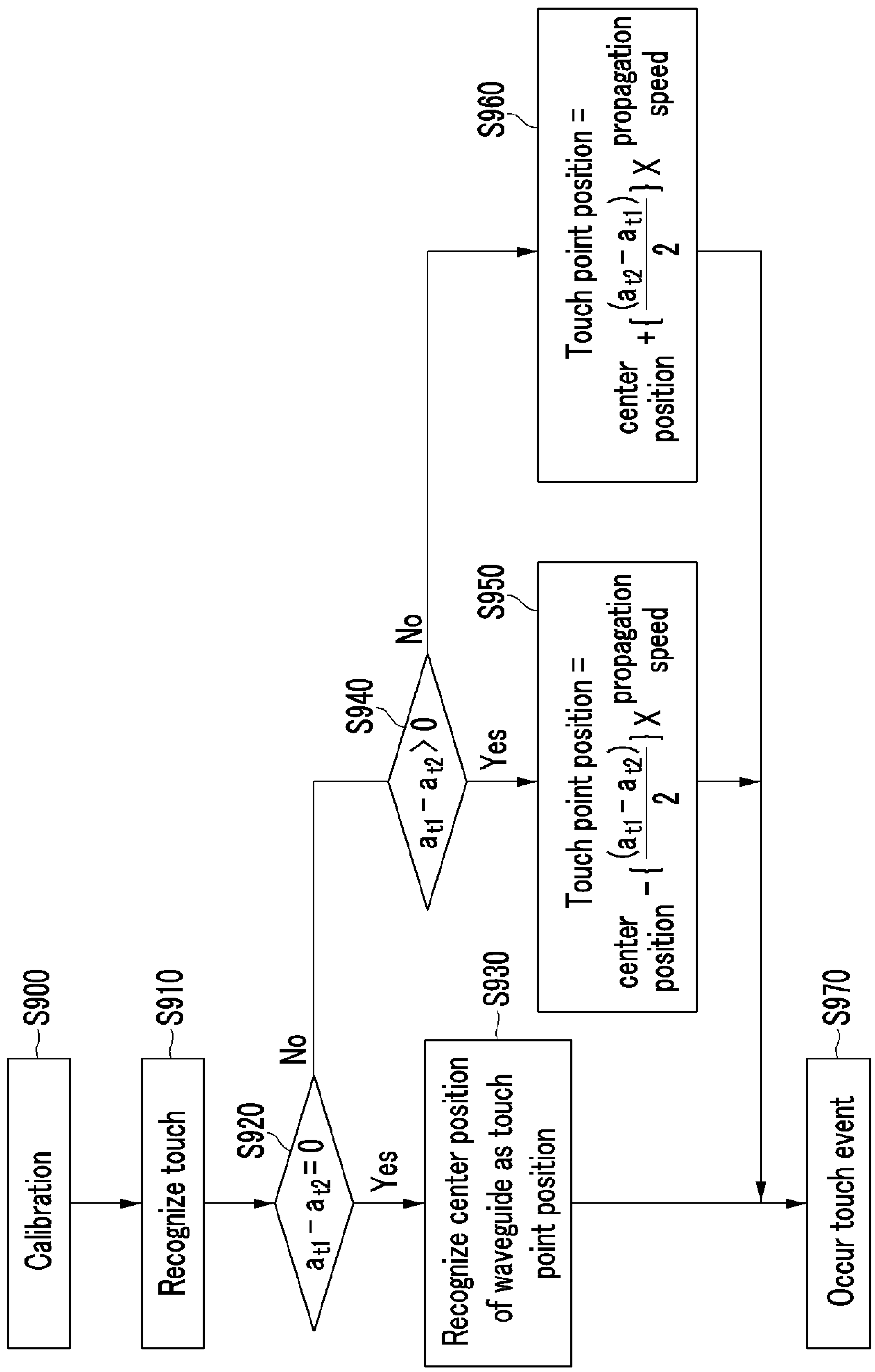

S900
Calibration
S910
Recognize touch
S920
$a_{t1} - a_{t2} = 0$
Yes
No
S930
Recognize center position of waveguide as touch point position
S940
$a_{t1} - a_{t2} > 0$
Yes
No
S950
Touch point position = center position $- \{\frac{(a_{t1} - a_{t2})}{2}\} \times$ propagation speed
S960
Touch point position = center position $+ \{\frac{(a_{t2} - a_{t1})}{2}\} \times$ propagation speed
S970
Occur touch event

FIG. 13

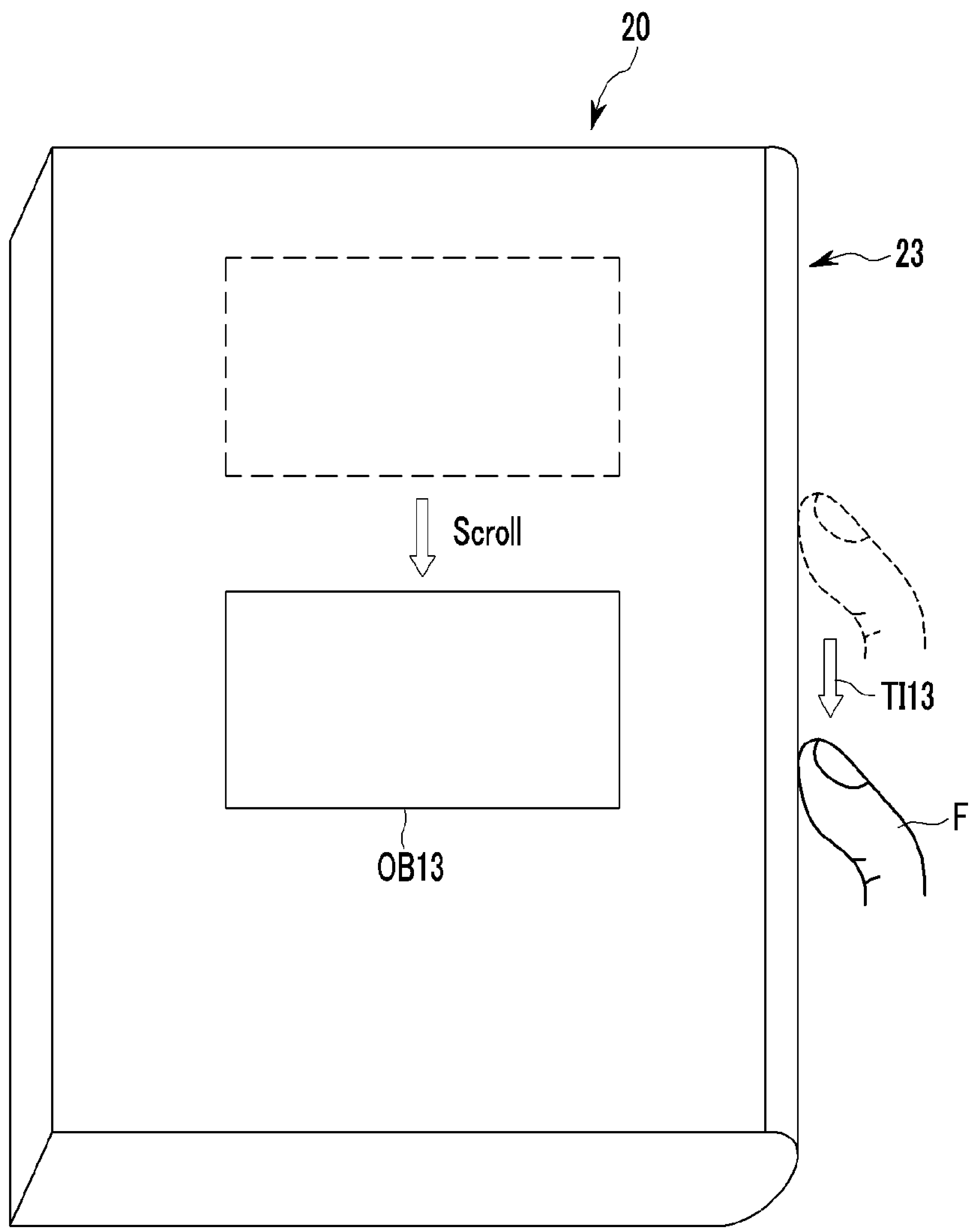


FIG. 14

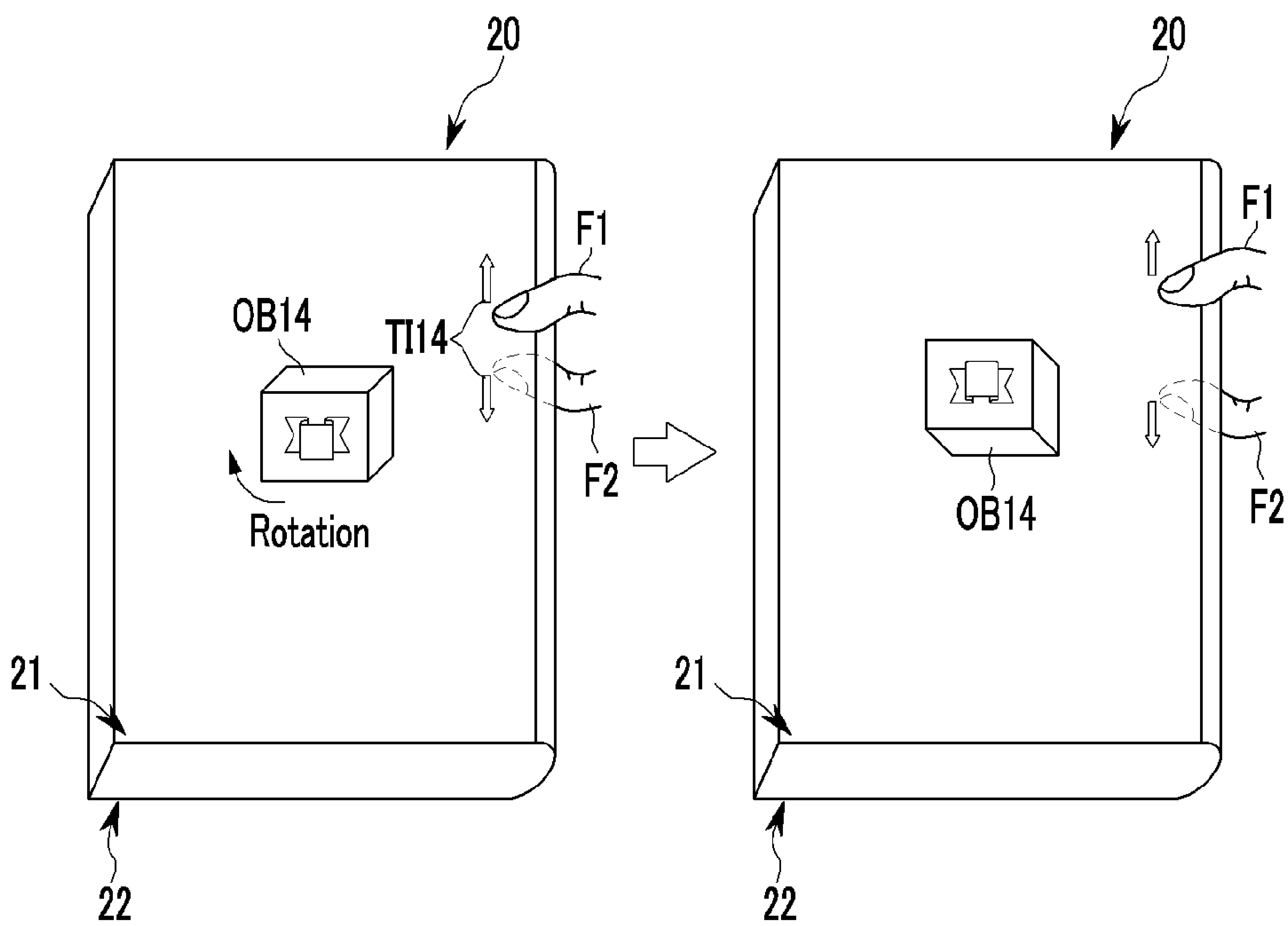


FIG. 15A

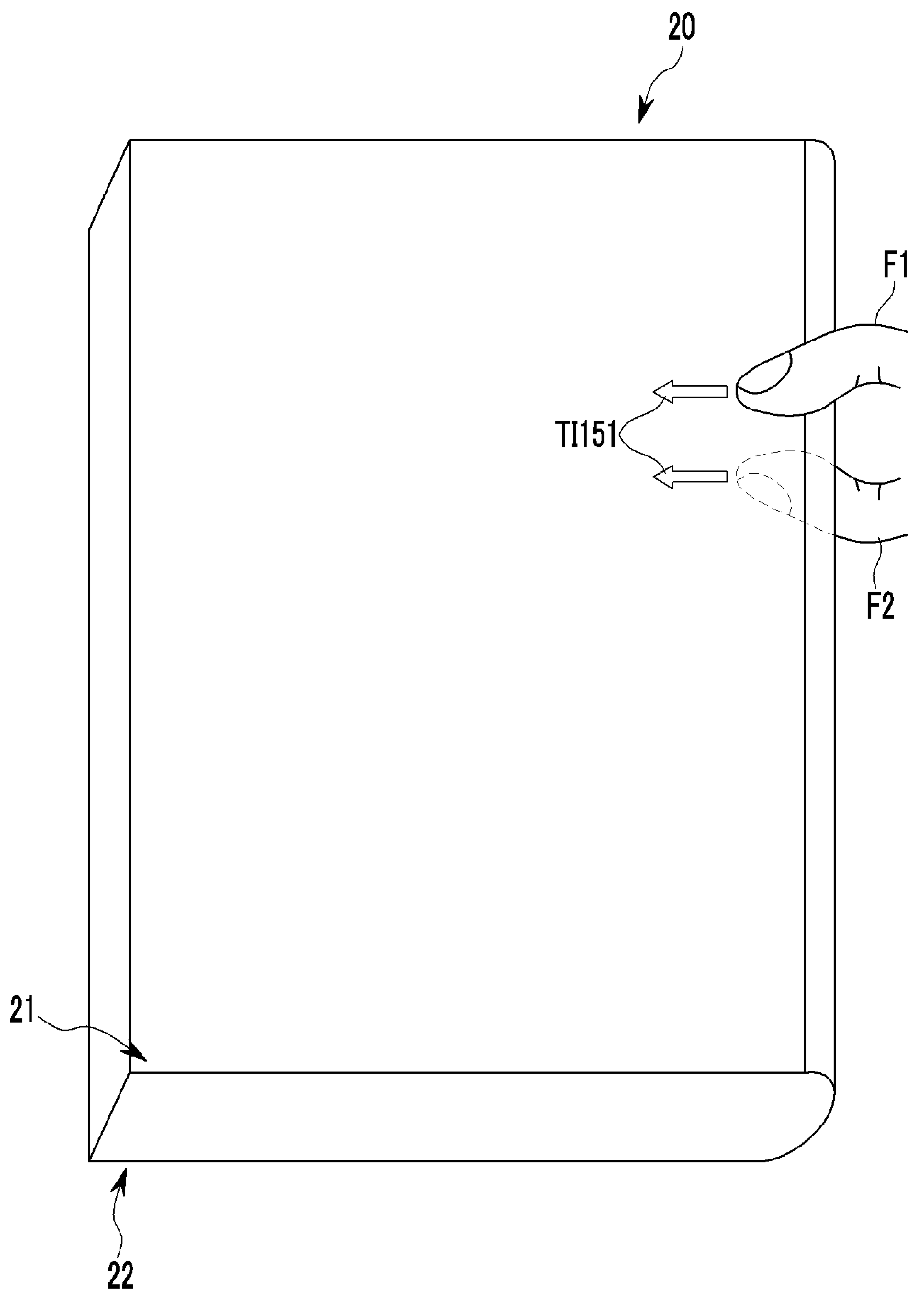


FIG. 15B

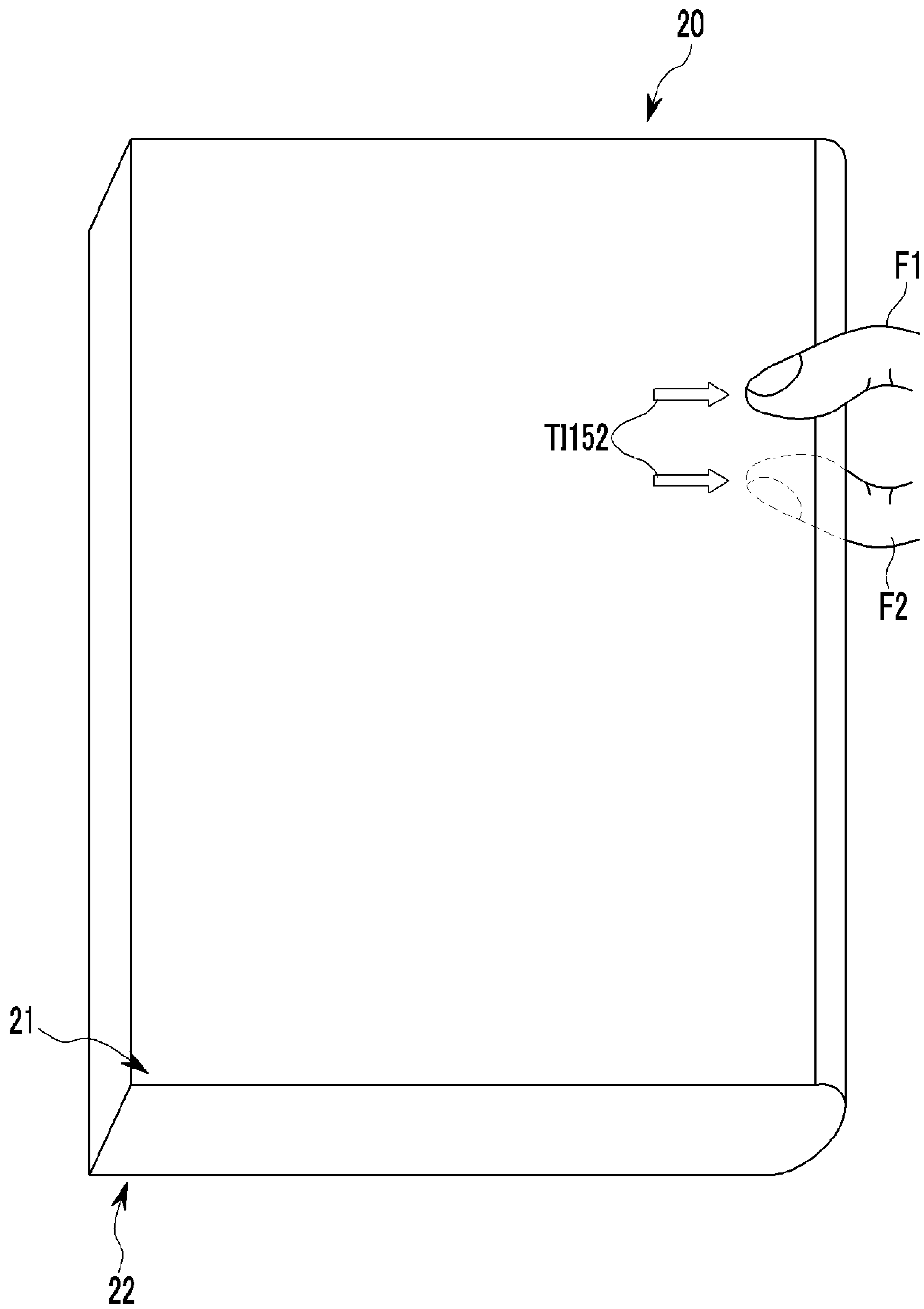


FIG. 16A

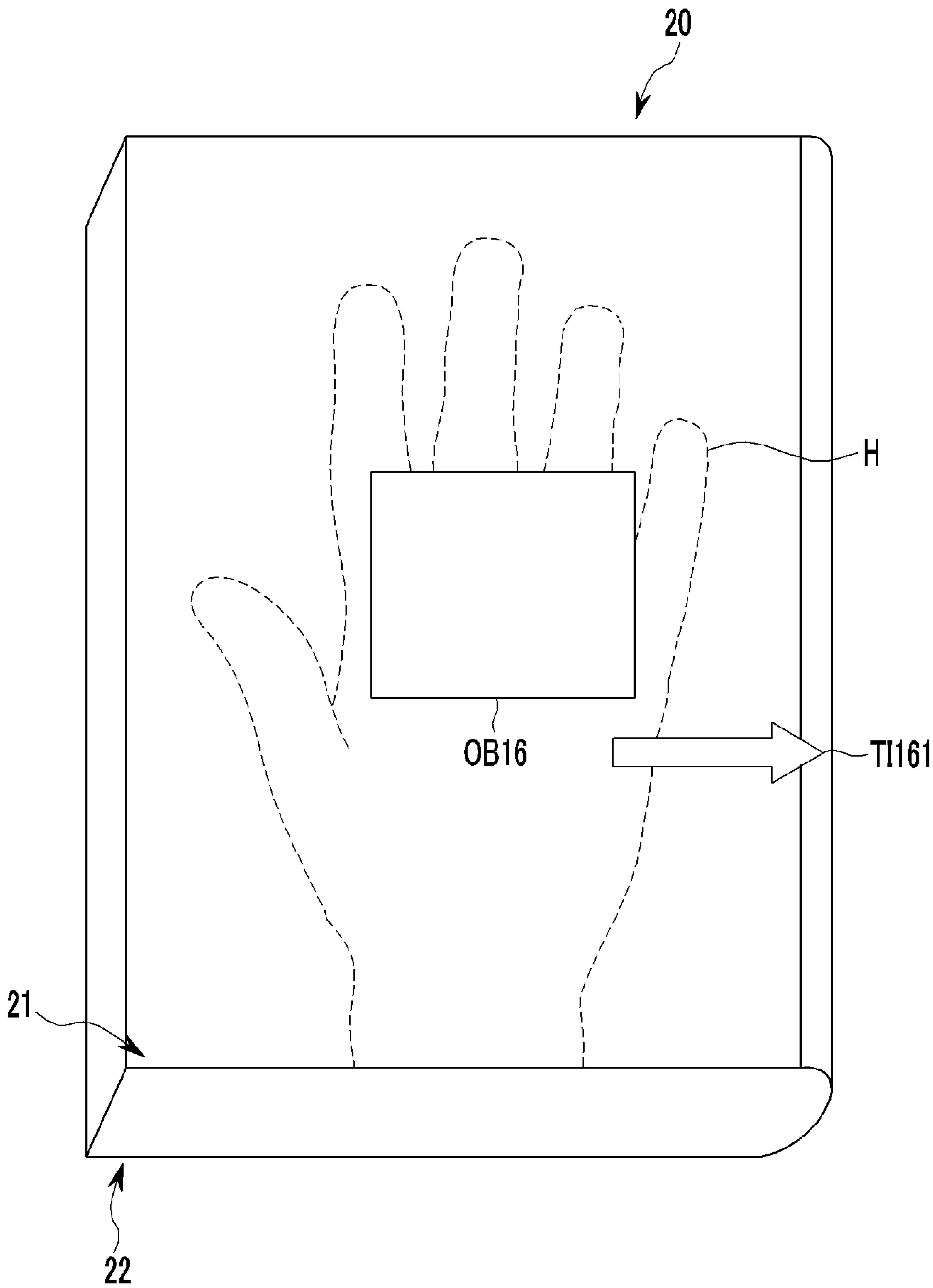


FIG. 16B

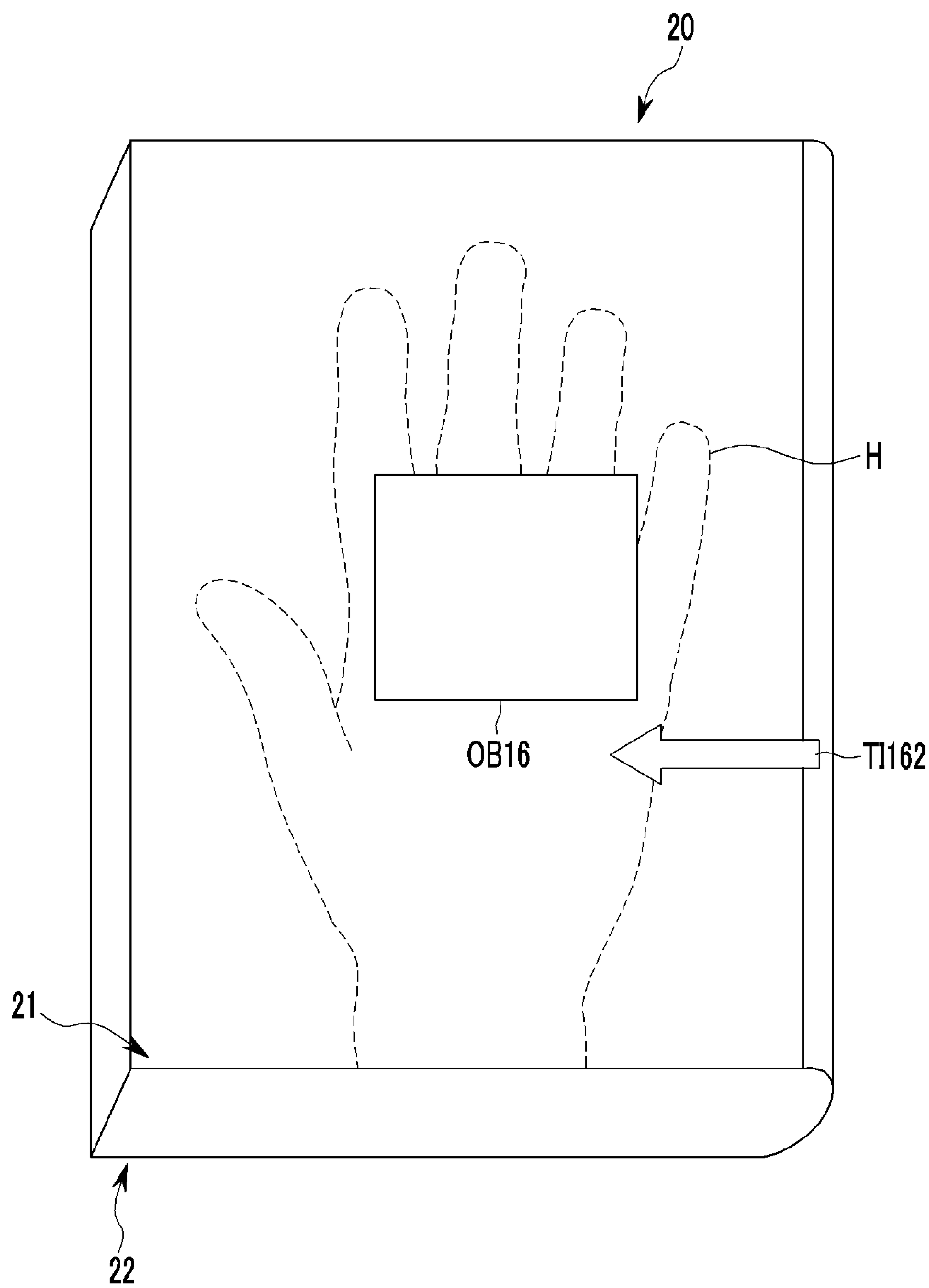


FIG. 17

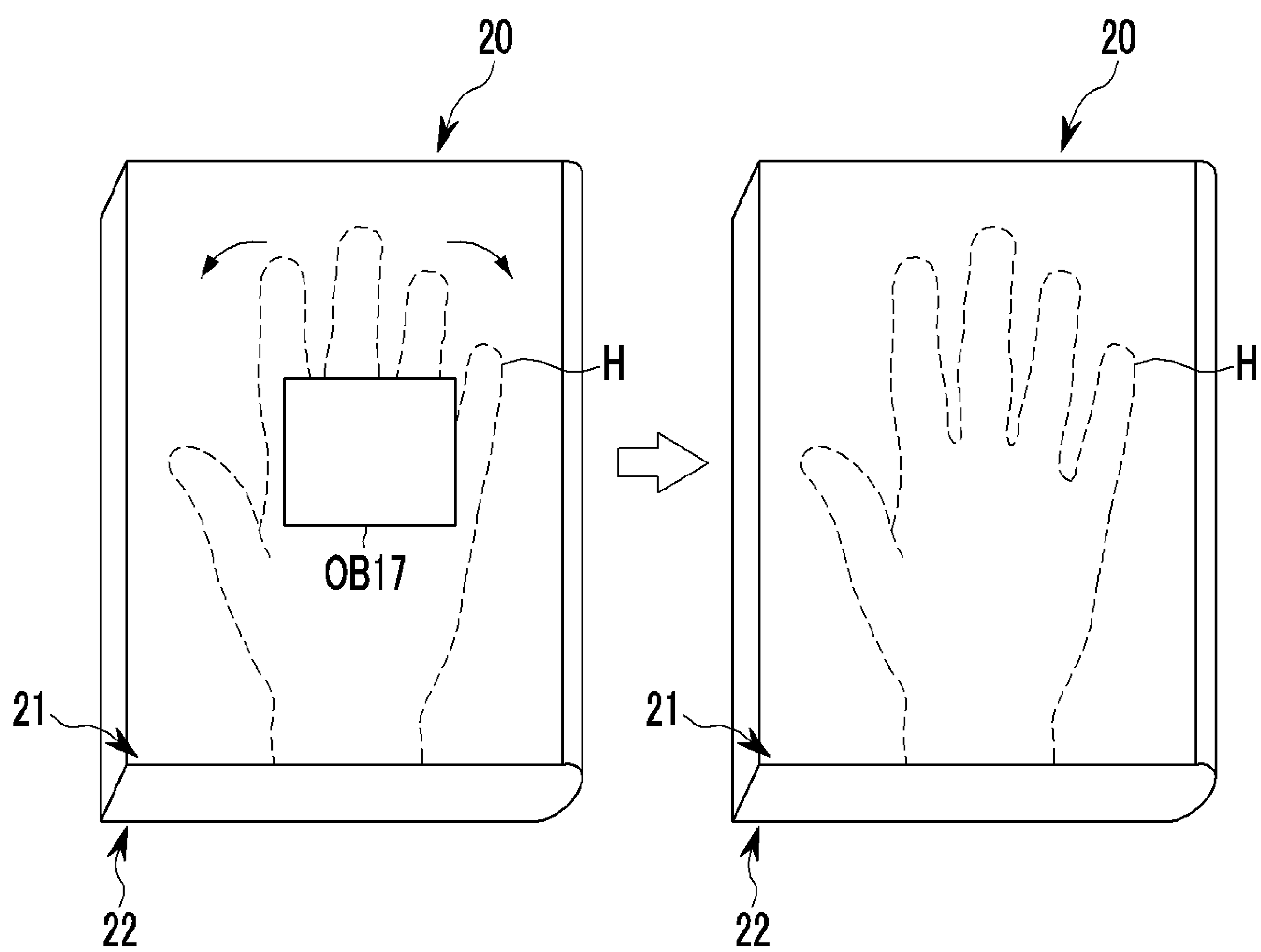
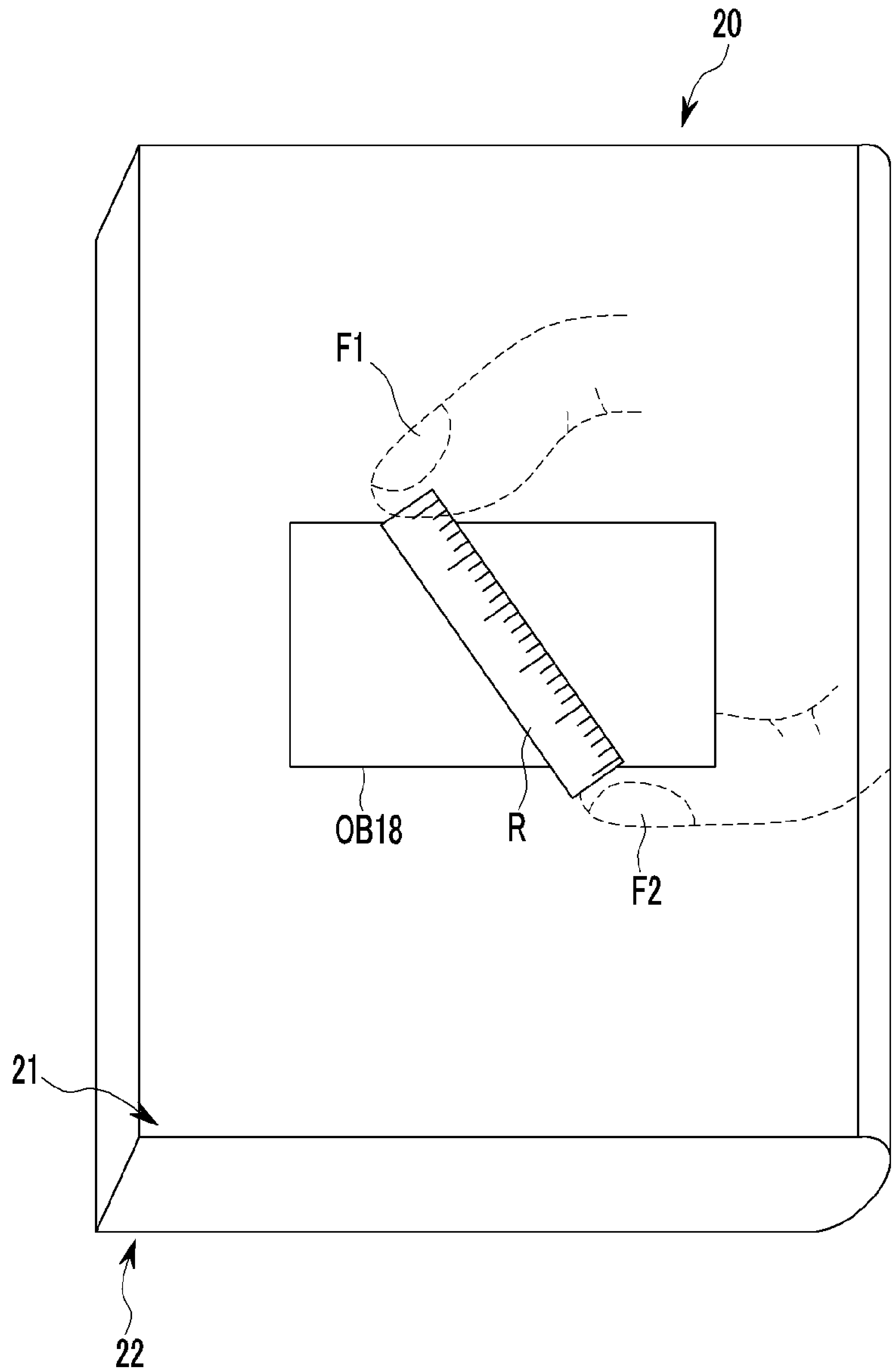


FIG. 18



TOUCH DEVICE AND DISPLAY DEVICE INCLUDING THE SAME

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority to and the benefit of Korean Patent Application No. 10-2015-0030006 filed in the Korean Intellectual Property Office on Mar. 3, 2015, the entire contents of which are incorporated herein by reference.

BACKGROUND

(a) Field

The present inventive concept relates to a touch device and a display device including the same. More particularly, the present inventive concept relates to a touch device and a display device including the same that enable a multiple surface touch.

(b) Description of the Related Art

A touch device integrated or combined to a display device provides an interaction system to the display device. In the display device, when a graphic image is displayed on a display panel, a user may touch a screen of the display device (using an active stylus, a passive stylus, or a part of his or her body such as a finger) to interact with the display device, thereby providing an intuitive user interface.

Recently, display devices that enable a touch input on a back or lateral surface as well as on a front surface have been developed. When a typical touch panel such as a capacitive, resistive, or pressure sensitive type is applied to the display device, in order to enable a multiple surface touch (or a multiple surface touch input), it is required that a touch panel be provided in each surface of the display device to receive a touch input. Further, a plurality of touch sensing drivers are required to separately drive the touch panels provided in multiple surfaces. Increment of the touch panels and the drivers for supporting a multiple surface touch increases size and cost of the display device. Further, when a multiple surface touch is applied to a transparent display, transmittance may deteriorate due to a touch panel, and since electrode patterns of the touch panel are viewed by a user, visibility may deteriorate.

The above information disclosed in this Background section is only for enhancement of understanding of the background of the inventive concept and therefore it may contain information that does not form the prior art.

SUMMARY

The present inventive concept has been made in an effort to provide a touch device and a display device including the same that enable a multiple surface touch.

An exemplary embodiment of the present inventive concept provides a touch device including: a first substrate; a second substrate facing the first substrate, and disposed to be spaced apart from the first substrate by a predetermined interval; a third substrate connecting first end portions of the first and second substrates to each other, and propagating an ultrasonic signal along the first substrate to the second substrate; a plurality of first ultrasonic transducers connected to second portions facing the first end portions in the first substrate, and propagating an ultrasonic signal to the first substrate; and a plurality of second ultrasonic transducers connected to the second portions facing the first end portions in the second substrate and receiving an ultrasonic signal propagated along the second substrate, wherein a touch point may be detected based on signal intensity variations of ultrasonic signals received by the second ultrasonic transducers.

A display device according to an exemplary embodiment of the present inventive concept includes the touch device and a display panel, wherein a front surface, a back surface, and one lateral surface of the display panel may be covered by the first, second, and third substrates of the touch device.

Another embodiment of the present inventive concept provides: a waveguide, as a medium propagating an ultrasonic signal, disposed in a zigzag form to cover at least two surfaces connected to each other in a panel; a first inter-digital transducer and a second inter-digital transducer respectively combined with a first end portion and a second end portion of the waveguide, and propagating the ultrasonic signal to the first end portion and the second end portion; and a first ultrasonic receiving transducer and a second ultrasonic receiving transducer respectively combined with the first end portion and the second end portion, and receiving an ultrasonic signal propagated along the waveguide, wherein a touch point is detected based on a time difference between a first time point at which a signal intensity variation of greater than or equal to a threshold value in an ultrasonic signal received by the first ultrasonic receiving transducer is detected and a second time point at which the signal intensity variation of greater than or equal to the threshold value in an ultrasonic signal received by the second ultrasonic receiving transducer is detected.

According to an embodiment of the present inventive concept, it is possible to minimize a cost increase due to a configuration for the multiple surface touches by one touch panel covering the front, back, and at least one lateral surface of the display panel, and by one driver driving the touch panel.

In addition, since transparent electrodes and metal electrodes of the touch panel are not formed on the display panel, transmittance deterioration due to the touch electrodes or moiré due to regularity of the touch electrodes may be prevented.

Further, since the touch input on the lateral surface or the back surface of the display device may be performed, it is possible to execute a touch gesture regardless of information being displayed on the display surface.

Further, it is possible to provide various and intuitive user interfaces by applying the multiple surface touch.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A is a schematic diagram for explaining a total reflection condition of an ultrasonic signal.

FIG. **1**B is a schematic diagram for explaining a touch detecting method using an ultrasonic signal according to an exemplary embodiment of the present inventive concept.

FIG. **2** is a schematic block diagram of a display device according to a first exemplary embodiment of the present inventive concept.

FIG. **3**A is a schematic perspective view of a touch panel **200** according to the first exemplary embodiment of the present inventive concept.

FIG. **3**B is a schematic cross-sectional view of the touch panel **200** according to the first exemplary embodiment of the present inventive concept.

FIG. **3**C schematically illustrates a path of an ultrasonic signal propagated along a waveguide in the touch panel **200** according to the first exemplary embodiment of the present inventive concept.

FIG. **4** illustrates an exemplary variation of the touch panel **200** according to the first exemplary embodiment of the present inventive concept.

FIG. **5**A illustrates another exemplary variation of the touch panel **200** according to the first exemplary embodiment of the present inventive concept.

FIGS. **5**B, **5**C and **5**D are schematic diagrams for explaining a guide bar included in the touch panel **200** shown in FIG. **5**A.

FIGS. **6**A, **6**B, **6**C and FIG. **6**D are schematic diagrams for explaining a method of obtaining a touch coordinate (value) in the touch device according to the first exemplary embodiment of the present inventive concept.

FIG. **7** illustrates a further exemplary variation of the touch panel **200** according to the first exemplary embodiment of the present inventive concept.

FIG. **8** is a flowchart of a touch detecting method of a touch device according to an exemplary embodiment of the present inventive concept.

FIG. **9** is a schematic block diagram of a display device according to a second exemplary embodiment of the present inventive concept.

FIG. **10**A is a schematic perspective view of a touch panel according to a second exemplary embodiment of the present inventive concept.

FIG. **10**B is a perspective view illustrating a waveguide of the touch panel according to the second exemplary embodiment of the present inventive concept in an unfolded state.

FIG. **10**C is a schematic top plan view illustrating the touch panel according to the second exemplary embodiment of the present inventive concept in an unfolded state.

FIGS. **11**A, **11**B and **11**C are schematic diagrams illustrating methods of obtaining touch coordinate values by the touch device according to the second exemplary embodiment of the present inventive concept.

FIG. **12** is a flowchart of a touch detecting method of the touch device according to the second exemplary embodiment of the present inventive concept.

FIG. **13** illustrates an example of scrolling a display surface (or a screen) by a lateral touch input in the display device according to the exemplary embodiments of the present inventive concept.

FIGS. **14**, **15**A and **15**B illustrate examples of providing a user interface for touch inputs on both surfaces in the display device according to the exemplary embodiments of the present inventive concept.

FIGS. **16**A, **16**B, **17** and **18** illustrate examples of providing a user interface for a touch input on a back surface in the display device according to the exemplary embodiments of the present inventive concept.

DETAILED DESCRIPTION OF THE EMBODIMENTS

Hereinafter, an exemplary embodiment of the present inventive concept will be described in detail with reference to the attached drawings such that the present inventive concept can be easily put into practice by those skilled in the art. As those skilled in the art would realize, the described embodiments may be modified in various different ways, all without departing from the spirit or scope of the present inventive concept.

The drawings and description are to be regarded as illustrative in nature and not restrictive. Like reference numerals designate like elements throughout the specification.

Throughout this specification and the claims that follow, when it is described that an element is "coupled" to another element, the element may be "directly coupled" to the other element or "electrically coupled" to the other element through a third element. In addition, unless explicitly described to the contrary, the word "comprise" and variations such as "comprises" or "comprising" will be understood to imply the inclusion of stated elements but not the exclusion of any other elements.

FIG. **1**A is a schematic diagram for explaining a total reflection condition of an ultrasonic signal.

Referring to FIG. **1**A, ultrasonic signals (**101**, **102**, **103**, **104**, and **105**) outputted from an ultrasonic source S are refracted or reflected depending on an incidence angle θ**1** to boundary surfaces **100** of a medium **1** and a medium **2** having different acoustic impedances.

At least part of the ultrasonic signal **102** incidents to the boundary surface **100** at a smaller incidence angle than a critical incidence angle is refracted on the boundary surface **100** and proceeds to the medium **2**.

At least part of the ultrasonic signal **103** incidents to the boundary surface **100** at the critical incidence angle is refracted on the boundary surface **100** at a 90° angle of refraction and proceeds in parallel with a boundary of the first medium (Medium **1**) and the second medium (Medium **2**).

At least part of the ultrasonic signals **103**, **104**, and **105** that are incident to the boundary surface **100** at an incidence angle equal to or greater than the critical incidence angle is reflected at the boundary surface **100** at a reflecting angle equal to the incidence angle and proceeds to the medium **1**.

The ultrasonic signals **104** and **105** incident to the boundary surface **100** at a greater incidence angle than the critical incidence angle are totally reflected at the boundary surface **100**, and proceed to the medium **1**. That is, energy of the ultrasonic signals **104** and **105** incident to the boundary surface **100** at the greater incidence angle than the critical incidence angle are totally reflected at the boundary surface **100** in an ideal condition.

When the medium **1** and the medium **2** are glass and air, respectively, an ultrasonic signal is refracted on the boundary surface **100** at a refraction angle of 50° when the ultrasonic signal is incident thereto at an incidence angle of 10°. Further, when the ultrasonic signal is incident to the boundary surface **100** at 15°, the ultrasonic signal is refracted on the boundary surface **100** at 90° and proceeds in parallel with the boundary surface **100** between the mediums **1** and **2**.

When the medium **1** and the medium **2** are glass and air, respectively, and a critical incidence angle of an ultrasonic signal is 15°, the ultrasonic signal is totally reflected without refraction when the ultrasonic signal is incident at an angle of greater than 15°.

An exemplary embodiment of the present inventive concept senses a touch signal using transmitting characteristics of an ultrasonic signal.

FIG. **1**B is a schematic diagram for explaining a touch detecting method using an ultrasonic signal according to an exemplary embodiment of the present inventive concept.

Referring to FIG. **1**B, an ultrasonic signal **111** outputted from an ultrasonic source S is incident to a boundary surface **100** of a medium **1** and a medium **2** having different acoustic impedances at an incidence angle θ**1** that is greater than a critical incidence angle. Accordingly, the ultrasonic signal **111** is totally reflected at the boundary surface **100**, and propagates to the medium **1**.

In this case, when a user's finger **112** is touched the boundary surface **100** of the two mediums, that is, the surface of the medium **1**, the total reflection of the ultrasonic signal **111** is disturbed by the user's finger **112**, such that energy of the ultrasonic signal is leaked. Accordingly, while the ultrasonic signal **111** is reflected on the boundary surface **100**, energy loss due to a touch may occur.

Energy of the ultrasonic signal may be obtained by measuring intensity of the ultrasonic signal. Accordingly, in the exemplary embodiment of the present inventive concept, a receiver receiving the ultrasonic signal detects intensity of the ultrasonic signal propagated through the medium **1**, and determines whether a touch has occurred based on the detected intensity.

Hereinafter, a touch device and a display device including the touch device according to a first exemplary embodiment of the present inventive concept will be described in detail with reference to FIGS. **2** to **8**.

FIG. **2** is a schematic block diagram of a display device according to a first exemplary embodiment of the present inventive concept. FIG. **3**A is a schematic perspective view of a touch panel **200** according to the first exemplary embodiment of the present inventive concept, and FIG. **3**B is a schematic cross-sectional view of the touch panel **200** according to the first exemplary embodiment of the present inventive concept. FIG. **3**C schematically illustrates a path of an ultrasonic signal propagated along a waveguide in the touch panel **200** according to the first exemplary embodiment of the present inventive concept. FIGS. **4**, **5**A, and **7** illustrate exemplary variations of the touch panel **200** according to a first exemplary embodiment of the present inventive concept, respectively. FIGS. **5**B to **5**D are schematic diagrams for explaining a guide bar included in the touch panel **200** shown in FIG. **5**A. FIGS. **6**A to **6**D are schematic diagrams for explaining a method for obtaining a touch coordinate in the touch device according to the first exemplary embodiment of the present inventive concept. FIG. **8** is a flowchart of a touch detecting method of a touch device according to an exemplary embodiment of the present inventive concept.

Referring to FIG. **2**, a display device **20** according to the first exemplary embodiment of the present inventive concept may include a touch device, a display panel **240**, and an application processor **250**.

Further, the touch device according to the first exemplary embodiment of the present inventive concept includes a touch panel **200** that includes a waveguide **210**, an inter-digital transducer (IDT) **211**, and an ultrasonic receiving transducer **212**, an ultrasonic transmitter **221**, an ultrasonic receiver **222**, and a touch controller **230**. The touch device according to the first exemplary embodiment of the present inventive concept is not limited to constituent elements shown in FIG. **2**, and may include more or fewer constituent elements than constituent elements shown in FIG. **2**.

The waveguide **210** includes a front waveguide **201**, a back waveguide **202**, and a bridge waveguide **203**. The front waveguide **201**, the back waveguide **202**, and the bridge waveguide **203** are mediums through which an ultrasonic signal may be propagated.

For better understanding and ease of description, although the waveguide **210** of the touch panel **200** is show in an unfolded state in FIG. **2**, the waveguide **210** according to the exemplary embodiment of the present inventive concept may be folded to surround a front surface, a back surface, and at least one side surface of the display panel **240**.

Referring to FIGS. **3**A and **3**B, the front waveguide **201** and the back waveguide **202** have a plate shape, and are disposed to be spaced apart from each other by a predetermined interval while facing each other. The display panel **240** is interposed between the front waveguide **201** and the back waveguide **202**. The front waveguide **201** is disposed to face the front surface of the display panel **240** to cover the front surface of the display panel **240**. The back waveguide **202** is disposed to face the back surface of the display panel **240** to cover the back surface of the display panel **240**. The front and back waveguides **201** and **202** guide an ultrasonic signal so that the ultrasonic signal may be propagated along the front and back surfaces of the display panel **240**.

Assistant layers **321** and **322** are respectively provided at a surface of the front waveguide **201** contacting the display panel **240** and at a surface of the back waveguide **202** contacting the display panel **240**. The assistant layers **321** and **322** may be made of a material with different acoustic impedance from that of the front waveguide **201** or the back waveguide **202** by a predetermined value so that the ultrasonic signal may propagated within the waveguide **210** of the touch device.

The bridge waveguide **203** connects one end portion of the front waveguide **201** and one end portion of the back waveguide **202**, and propagates an ultrasonic signal passing through the front waveguide **201** toward the back waveguide **202**.

The bridge waveguide **203** is formed to surround at least one lateral surface of the display panel **240**. Accordingly, the ultrasonic signal passing through the front waveguide **201** may be propagated to the bridge waveguide **203**. Further, the ultrasonic signal propagated to the bridge waveguide **203** is propagated along the one lateral surface of the display panel **240** by the bridge waveguide **203** to be transmitted to the back waveguide **202**.

Referring to FIG. **3**C, when an ultrasonic signal **5** generated by the inter-digital transducer **211** passes through the front waveguide **201** and is incident on the bridge waveguide, the bridge waveguide **203** totally reflects the incident ultrasonic signal and guides the totally reflected ultrasonic signal in a thickness direction of the display panel **240**, that is, a third direction. Further, the bridge waveguide **203** again totally reflects the ultrasonic signal **5** that is totally reflected in the thickness direction of the display panel **240** and propagates it to the back waveguide **202**.

The bridge waveguide **203** may have various shapes, and may be formed to surround one lateral surface of the display panel **240**. Further, the bridge waveguide **203** is formed in a shape such that it may totally reflect the ultrasonic signal **5** passing through the front waveguide **201**, may guide the totally reflected ultrasonic signal in the third direction, and may again totally reflect the guided ultrasonic signal to be incident on the back waveguide **202** at a predetermined angle which is greater than the critical incidence angle.

As shown in FIGS. **3**B and **3**C, the bridge waveguide **203** may include an outer curved surface that connects an outer surface of the front waveguide **201** and an outer surface of the back waveguide **202** in a curved line form.

As shown in FIG. **4**, a bridge waveguide **203'** may include at least one outer flat surface that linearly connects the front waveguide **201** and the back waveguide **202**.

The front waveguide **201**, the back waveguide **202**, and the bridge waveguide **203** are made of a medium with the same acoustic impedance so that ultrasonic signals may be propagated within the waveguide **210** of the touch panel **200**.

Kinds of mediums forming the front waveguide **201**, the back waveguide **202**, and the bridge waveguide **203** is not limited, but a material of which the acoustic impedance differs from that of external air by more than a predetermined value may be used so that less loss of signal my occur when an ultrasonic signal is propagated.

When the display panel **240** is a transparent display panel, the front waveguide **201**, the back waveguide **202**, and the bridge waveguide **203** may be made of a transparent material. When the display panel **240** is an opaque display panel, the front waveguide **202** may be made of a transparent material, and the back waveguide **202** and the bridge waveguide **203** may be made of a transparent or opaque material.

The front waveguide **201**, the back waveguide **202**, and the bridge waveguide **203** may be made of glass, plastic, a polymer, or the like.

On the other hand, the front waveguide **201**, the back waveguide **202**, and the bridge waveguide **203** may be integrally formed. In this case, the front waveguide **201**, the back waveguide **202**, and the bridge waveguide **203** may be made by folding one substrate to cover a front surface, a back surface and at least one side surface of the display panel **240** as shown in FIG. **3**A.

In addition, the front waveguide **201**, the back waveguide **202**, and the bridge waveguide **203** may be separately formed, and then be combined into one piece. In this case, after the front and back waveguides **201** and **202** are respectively formed in a plate shape, the bridge waveguide **203** may be combined with the front and back waveguides **201** and **202** to cover at least one side surface of the display panel **240** as shown in FIG. **3**A.

In the specification, the front and back waveguides **201** and **202** that guide the ultrasonic signal in the touch panel **200** are illustrated to be provided separately from the display panel **240**, but the exemplary embodiments of the present inventive concept are not limited thereto. That is, the waveguide of the touch panel **200** may be realized with some of constituent elements of the display panel such as a substrate, a cover window, and a cover lens of the display panel. In this case, since an increase in the thickness of a display device due to supplemental waveguide may be minimized, the thickness of the display device may decrease.

Referring back to FIGS. **2** and **3**A, at least one inter-digital transducer (IDT) **211** is disposed at an end portion of the front waveguide **201** facing the bridge waveguide **203**. The inter-digital transducer **211** may be an actuator that converts an electrical signal into a vibration signal to generate an ultrasonic signal. The inter-digital transducer **211** may include a piezoelectric substrate and an electrode formed on the piezoelectric substrate.

Referring to FIG. **3**A, a plurality of inter-digital transducers **211** are disposed to be spaced apart from each other by a predetermined interval in a second direction along the end portion of the front waveguide **201**. The inter-digital transducers **211** generate an ultrasonic signal and provide the generated ultrasonic signal to the end portion of the front waveguide **201**. The ultrasonic signal generated by the inter-digital transducer **211** is propagated to the front waveguide **201**.

The ultrasonic signal generated by the inter-digital transducer **211** is propagated along the front waveguide **201**, the bridge waveguide **203**, and the back waveguide **202**.

At least one ultrasonic receiving transducer **212** is disposed at an end portion of the back waveguide **202** facing the bridge waveguide **203**. Referring to FIG. **3**A, a plurality of ultrasonic receiving transducers **212** are disposed to be spaced apart from each other by a predetermined interval in the second direction along the end portion of the back waveguide **202**.

The ultrasonic receiving transducer **212** may be an actuator that converts a vibration signal which is an ultrasonic signal into an electrical signal. The ultrasonic receiving transducer **212** may include a piezoelectric substrate and an electrode formed on the piezoelectric substrate.

The ultrasonic receiving transducer **212** receives the vibration signal corresponding to the ultrasonic signal that is generated by the inter-digital transducer **211** and then is propagated along the front waveguide **201**, the bridge waveguide **203**, and the back waveguide **202**. Further, after receiving the vibration signal, the ultrasonic receiving transducer **212** converts the received vibration signal into an electrical signal and then outputs the converted electrical signal to the touch controller **230**.

In FIG. **3**A, the inter-digital transducer **211** and the ultrasonic receiving transducer **212** are shown to be disposed in the same number, but the exemplary embodiment of the present inventive concept is not limited thereto. That is, the number of the inter-digital transducers **211** may be fewer than that of the ultrasonic receiving transducer **212**.

In addition, the touch panel **200** may further include a guide bar so that ultrasonic signals generated by the inter-digital transducers **211** of the fewer number (e.g., two) may be propagated throughout an entire region of the waveguide **210**. Referring to FIG. **5**A, a guide bar **510** is disposed at both end portions of the front waveguide **201** facing the bridge waveguide **203**. Two inter-digital transducers **211** are respectively disposed at opposite sides of the guide bar **510**. The inter-digital transducers **211** disposed at the opposite sides of the guide bar **510** generate ultrasonic signals, and propagate the generated ultrasonic signals to the guide bar **510**. Referring to FIG. **5**B, a lens array **511** is provided at one surface of the guide bar **510** which does not face the front waveguide **201**. A propagation path of the ultrasonic signal **5** propagated to the guide bar **510** by the inter-digital transducer **211** is changed in the first direction by the lens array **511** formed at an outer surface of the guide bar **510**. Accordingly, the ultrasonic signal **5** generated by the inter-digital transducer **211** is spread and propagated throughout the entire region of the front waveguide **201**. As shown in FIG. **5**C, convex portions **512** with a convex lens shape may be formed at one surface of the guide bar **510** which faces the surface on which the lens array **511** is formed and faces the end portion of the front waveguide **201**. Further, as shown in FIG. **5**D, a plurality of convex lens **520** may be combined with the one surface of the guide bar **510** which faces the end portion of the front waveguide **201**. The convex portion **512** or the convex lens **520** of the guide bar **510** serves to focus the ultrasonic signal in a thickness direction (a third direction) of the front waveguide **201** so that incident efficiency of the ultrasonic signal may be improved.

Referring back to FIG. **2**, the ultrasonic transmitter **221** is connected to the plurality of inter-digital transducers **211**. The ultrasonic transmitter **221** provides the inter-digital transducers **211** with a driving signal (driving voltage) to generate an ultrasonic signal.

The ultrasonic receiver **222** is connected to the plurality of ultrasonic receiving transducers **212**. The ultrasonic receiver **222** processes electrical signals received through the ultrasonic receiving transducers **212** to generate touch signals. A gain of an electrical signal outputted from the ultrasonic receiving transducer **212** is determined depending on intensity of an ultrasonic signal received by the ultrasonic receiving transducer **212**. That is, as the intensity of the ultrasonic signal received by the ultrasonic receiving transducer **212** is greater, the gain of the electrical signal outputted from the ultrasonic receiving transducer **212** increases. The ultrasonic receiver **222** generates a touch signal which includes distribution of intensity of ultrasonic signals depending on a receiving position according to electrical signals outputted from the ultrasonic receiving transducer **212**.

The ultrasonic receiver **222** is connected to the touch controller **230**. The ultrasonic receiver **222** outputs the touch signal to the touch controller **230**. The touch signal is a digital signal which is obtained from an analog signal outputted from the ultrasonic receiving transducers **212**.

The touch controller **230** processes a touch signal received from the ultrasonic receiver **222**, and outputs a touch event such as a touch coordinate of a touch point to the application processor **250**.

The touch controller **230** detects variation of intensity of the ultrasonic signal received by the ultrasonic receiving transducer **212** through the touch signal received by the ultrasonic receiver **222**. Further, the touch controller **230** detects a position of the ultrasonic receiving transducer **212** in which variation of signal intensity sufficient for detection of the touch event occurs, and obtains the touch coordinates of the touch point based on the detected position.

The intensity of the ultrasonic signal detected by each ultrasonic receiving transducer **212** is varied depending on whether any point of the waveguide **210** in which the ultrasonic signal is propagated is touched.

When the touch point is changed in a direction parallel to arrangement of the ultrasonic receiving transducers **212**, the position of the ultrasonic receiving transducer **212** that receives the ultrasonic signal of which the energy is lost due to a touch is changed. Accordingly, the touch controller **230** may detect an x coordinate (or a y coordinate) of the touch point based on the position of the ultrasonic receiving transducer **212** in which a signal intensity change greater than or equal to a threshold value is detected.

When the touch point is changed in a direction in which a distance from the ultrasonic receiving transducer **212** is changed, numbers of the ultrasonic receiving transducers **212** that receive the ultrasonic signal having reduced energy due to a touch and the signal intensity variation detected by the ultrasonic receiving transducer **212** are changed. For example, numbers of the ultrasonic receiving transducers **212** that receive the ultrasonic signals having reduced energy decrease when touch occurs closer to the ultrasonic receiving transducer **212**. In addition, when the ultrasonic signal having reduced energy due to the touch is reduced, the intensity change of the ultrasonic signal received by the ultrasonic receiving transducers **212** increases.

Accordingly, the touch controller **230** detects the y coordinate of the touch point based on the number and the signal intensity variation of the ultrasonic receiving transducers **212** in which the signal intensity greater than or equal to the threshold value is detected.

The touch controller **230** may calculate a touch area of a touch means such as a finger and a stylus based on the touch signal. An area in which the signal intensity of greater than or equal to the threshold value is detected by the ultrasonic receiving transducer **212** is varied depending on an area that the touch means touches the waveguide **210**. That is, the larger the touch area by the touch means, the larger the area in which the signal intensity variation of the ultrasonic signal is detected by the ultrasonic receiving transducer **212**. Accordingly, the touch controller **230** may calculate the touch area depending on the size of the area in which the signal intensity variation of the ultrasonic signal is detected by the ultrasonic receiving transducer **212**.

A method in which a touch controller **230** detects a touch coordinate will now be described in detail with reference to FIGS. **6**A to **6**D. FIGS. **6**A to **6**D graphically illustrate signal intensity of an ultrasonic signal received by each inter-digital transducer **212** when a touch occurs. That is, FIGS. **6**A to **6**D graphically illustrate the signal intensity of the ultrasonic signal depending on a receiving position at which the ultrasonic signal is received when the touch occurs. Further, FIGS. **6**A to **6**D illustrate a foldable waveguide **210** of a touch panel **200** in an unfolded state.

Referring to FIG. **6**A, when a point TP**11** corresponding to x**11** of x coordinates is touched, a signal intensity variation is detected by at least one ultrasonic receiving transducer **212** disposed around a receiving position corresponding to x**11** of the x coordinates. Similarly, when a point TP**12** corresponding to x**12** of x coordinates is touched, a signal intensity variation is detected by at least one ultrasonic receiving transducer **212** disposed around a receiving position corresponding to x**12** of the x coordinates. Accordingly, the touch controller **230** may detect the x coordinate values of the touch points TP**11** and TP**12** based on positions of ultrasonic receiving transducers **212** in which a signal intensity variation of greater than or equal to a threshold value is detected.

The touch controller **230** may detect a center of a receiving position at which a signal intensity variation of greater than or equal to a threshold value is detected as an x coordinate value of a touch point. Further, the touch controller **230** may detect an x coordinate value of a touch point from a receiving position (a position of an inter-digital transducer **212**) at which the greatest signal intensity variation occurs.

Referring to FIG. **6**B, when points TP**21**, TP**22**, and TP**23** that are different from each other in a y coordinate are touched, areas R**1**, R**2**, and R**3** of the ultrasonic receiving transducers **212** in which a signal intensity variation of greater than or equal to a threshold value is detected are different from each other. That is, when the points TP**21**, TP**22**, and TP**23** having different y coordinates are touched, numbers of the ultrasonic receiving transducers **212** in which the signal intensity variation of greater than or equal to the threshold value is detected may be different. As the y coordinate values of the touch point TP**21**, TP**22**, and TP**23** are farther from the ultrasonic receiving transducer **212**, a receiving range (or the number of ultrasonic receiving transducers **212**) in which the signal intensity variation of greater than or equal to the threshold value is detected increases.

When the different y coordinate points TP**21**, TP**22**, and TP**23** are touched, the signal intensity variations detected by the ultrasonic receiving transducers **212** are different from each other. As the y coordinate values of the touch points TP**21**, TP**22**, and TP**23** are closer to the ultrasonic receiving transducer **212**, the signal intensity variations of the ultrasonic signals detected by the ultrasonic receiving transducers **212** increase. Accordingly, the signal intensities I**1**, I**2**, and I**3** of the ultrasonic signals detected by the ultrasonic receiving transducers **212** decrease as the coordinate values of the touch points TP**21**, TP**22**, and TP**23** are closer to the ultrasonic receiving transducer **212**.

Therefore, the touch controller **230** may detect the y coordinate (value) of the touch point based on the area in which the signal intensity variation of greater than or equal to the threshold value is detected in the ultrasonic receiving transducer **212** (the number of ultrasonic receiving transducers **212** at which the signal intensity variation of greater than or equal to the threshold value is detected) and the signal intensity variation in the ultrasonic receiving transducer **212**.

In the present exemplary embodiment, the touch controller **230** may detect multiple touches through touch signals in the ultrasonic receiver **222**.

Referring to FIG. **6**C, when two different points TP**31** and TP**32** are simultaneously touched, a signal intensity distribution S3 of ultrasonic signals detected by the ultrasonic receiving transducers **212** includes two point at which the signal intensity variation of greater than or equal to the threshold value due to the two different touch points TP**31** and TP**32**. When the x coordinate values of the two touch points TP**31** and TP**32** are different from each other, the signal intensity distribution S3 of the ultrasonic signals detected by the ultrasonic receiving transducers **212** has two different signal intensity distributions S**31** and S**32** depending on a receiving position. The touch controller **230** discriminates between the signal intensity distributions S**31** and S**32** corresponding to respective touch points TP**31** and TP**32** depending on the receiving position, and obtains respective touch coordinate values of the touch points TP**31** and TP**32** based on the respective signal intensity distributions S**31** and S**32**.

Referring to FIG. **6**D, when the y coordinate values of two touch points TP**41** and TP**42** that are simultaneously touched are different, a signal intensity distribution S4 of the ultrasonic signals detected by the ultrasonic receiving transducers **212** has two signal intensity distributions S**41** and S**42** of which the signal intensity variations are different from each other. The touch controller **230** discriminates between the signal intensity distributions S**41** and S**42** corresponding to respective touch points TP**41** and TP**42** depending on the amounts of the signal intensity variations, and obtains respective touch coordinate values of the touch points TP**41** and TP**42** based on respective signal intensity distributions S**41** and S**42**.

As described above, the touch controller **230** obtains the signal intensity distribution according to the receiving position (the position of each ultrasonic receiving transducer **212**) based on the touch signal from the ultrasonic receiver **222**, thereby obtaining the touch coordinate value.

The ultrasonic receiving transducers **212** may set an initial signal intensity of the ultrasonic signal through calibration. Further, the touch controller **230** may detect a touch coordinate value based on an amount of variation between an initial signal intensity and the respective signal intensity distributions S**41** and S**42**. Accordingly, although the signal intensity of the ultrasonic signals received by the plurality of ultrasonic receiving transducers **212** is not uniform in a state without a touch, a touch coordinate value may be detected.

Referring back to FIG. **2**, the touch controller **230** outputs a touch event including a touch coordinate (value) to the application processor **250**.

When the application processor **250** receives the touch event from the touch controller **230**, the application processor **250** processes the touch event. Application software operated in the application processor **250** renders image data (or image frame) for displaying on the display panel **240** according to processing of the touch event received from the touch controller **230**.

The image data rendered by the application processor **250** are transmitted to the display panel **240** and displayed by the display panel **240**.

The display panel **240** displays the image data rendered by the application processor **250**.

The display panel **240** may be a transparent display panel. The transparent display panel maintains transparency with which an object positioned at a rear side of the display panel **240** is able to be viewed at the front of the display panel **240** while the transparent display panel does not display an image. Further, while the transparent display panel displays an image, the transparent display panel maintains a predetermined transparency.

The display panel **240** may be realized in various types such as a liquid crystal display (LCD) panel, a thin film transistor liquid crystal display (TFT-LCD) panel, a field emission display (FED) panel, an organic light emitting diode display (OLED) panel, a quantum dot display panel, and the like.

As described above, in the display device **20** according to the first exemplary embodiment of the present inventive concept, the front waveguides **201**, the back waveguides **202** with the same acoustic impedance and the bridge waveguide **203** connecting the waveguides **201** and **202** are disposed to surround the front, back, and side surfaces of the display panel **240** respectively. Further, the display device **20** detects the touch signal based on the signal intensity variation of the ultrasonic signal propagated through the waveguides **201**, **202**, and **203**. Accordingly, the display panel **240** may detect a touch input at the lateral surface as well as the front and back surfaces of the display panel **240**.

As shown in FIG. **3**A, in the first exemplary embodiment of the present inventive concept, the touch panel **200** includes one of the bridge waveguide **203** connecting the front waveguide **201** and the back waveguide **202**, but is not limited thereto.

The touch panel **200**, as shown in FIG. **7**, may be configured to include two bridge waveguides **203***a* and **203***b* connecting end portions of a front waveguide **201** and a back waveguide **202**. In this case, in the front and back waveguides **201** and **202**, a plurality of ultrasonic transmitting and receiving transducers **211***a* and **212***a* are respectively disposed at a first end portion facing the first bridge waveguide **203***a* and a plurality of ultrasonic transmitting and receiving transducers **211***b* and **212***b* are respectively disposed at a second end portion facing the second bridge waveguide **203***b*. Accordingly, an ultrasonic signal outputted from an inter-digital transducer **211***a* disposed at the first end portion of the front waveguide **201** and an ultrasonic signal outputted from an inter-digital transducer **211***b* disposed at the second end portion of the front waveguide **201** respectively propagate in directions crossing each other to be respectively detected by the ultrasonic receiving transducer **212***a* disposed at the first end portion of the back waveguide **202** and the ultrasonic receiving transducer **212***b* disposed at the second end portion of the back waveguide **202**. Accordingly, the touch controller **230** may detect both an x coordinate (value) and a y coordinate (value) of a touch point according to the method described with reference to FIG. **6**A. That is, the touch controller **230** may detect both the x coordinate value and the y coordinate value of the touch point from positions of ultrasonic receiving transducers **212***a* and **212***b* at which a signal intensity variation of an ultrasonic signal above a threshold value is detected.

According to the first exemplary embodiment of the present inventive concept, the touch controller **230** may recognize a grasping position of a user's fingers from the touch coordinate values, thereby calculating a touch estimating area. Further, the touch controller **230** may reduce power for the touch process by driving some of the inter-digital transducers **211** and the ultrasonic receiving transducers **212** depending on the calculated touch estimating area.

FIG. **8** is a flowchart of a touch detecting method of the touch device according to the first exemplary embodiment of the present inventive concept.

Referring to FIG. **8**, the touch device according to the first exemplary embodiment of the present inventive concept performs calibration of a receiving signal intensity of an ultrasonic signal (S**800**).

In the calibration step (S**800**), the inter-digital transducers **211** generate an ultrasonic signal in a state in which no touch occurs, and the ultrasonic receiving transducers **212** receive an ultrasonic signal propagated through the waveguide **210** of the touch device. Signal intensities of the ultrasonic signals received by respective ultrasonic receiving transducers **212** are stored as initial signal intensities for each ultrasonic receiving transducers **212**, and later, the initial signal intensities are used as a reference value for detecting a signal intensity variation of the ultrasonic signal.

When touch detection is started, the inter-digital transducers **211** continuously (or periodically) generate an ultrasonic signal, respectively. Further, the ultrasonic receiving transducers **212** continuously (or periodically) receive an ultrasonic signal propagated through the waveguide **210** of the touch device (S**810**). The ultrasonic signal received through the ultrasonic receiving transducers **212** is converted into a touch signal representing a signal intensity distribution according to a receiving position by the ultrasonic receiver **222**, and is transmitted to the touch controller **230** (S**820**).

The touch controller **230** analyzes the touch signal from the ultrasonic receiver **222**, and determines whether a signal intensity variation of greater than or equal to a threshold value occurs in the received ultrasonic signals. If the signal intensity variation of greater than or equal to the threshold value is detected in the received ultrasonic signals, the touch controller **230** determines that a touch occurs (S**830**).

When it is recognized that the touch occurs, the touch controller **230** determines, from the touch signal, a receiving position (a position of the ultrasonic receiving transducer **212**) at which the signal intensity variation occurs, and obtains an x coordinate value of the touch point through the detected receiving position (S**840**).

The touch controller **230**, at step S**840**, may determine, as the x coordinate value of the touch point, a center position of an area in which the signal intensity variation of greater than or equal to the threshold value of the ultrasonic signal is detected in the ultrasonic receiving transducers **212**.

The touch controller **230**, at step S**840**, may determine, as the x coordinate value of the touch point, a receiving position at which signal intensity variation of the ultrasonic signal has a maximum value (or an ultrasonic receiving transducer **212** at which signal intensity variation of the received ultrasonic signal has a maximum value).

The touch controller **230**, from the touch signal, determines a size of an area in which the signal intensity variation of greater than or equal to the threshold value of the ultrasonic signal is detected in the ultrasonic receiving transducers **212** (or the number of the ultrasonic transducers **212** at which the signal intensity variation of greater than or equal to the threshold value of the ultrasonic signal is detected), and a signal intensity variation amount of the ultrasonic signal. Further, the touch controller **230** obtains a y coordinate value based on the obtained size of the area in which the signal intensity variation of greater than or equal to the threshold value of the ultrasonic signal is detected, and the obtained signal intensity variation value of the ultrasonic signal (S**850**).

When the touch coordinate values are obtained through steps S**840** to S**850**, the touch controller **230** generates a touch event including the touch coordinate values (S**860**).

A touch device and a display device including the touch device according to a second exemplary embodiment of the present inventive concept will now be described in detail with reference to FIGS. **9** to **12**.

FIG. **9** is a schematic block diagram of a display device according to a second exemplary embodiment of the present inventive concept. FIG. **10**A is a schematic perspective view of a touch panel according to the second exemplary embodiment of the present inventive concept. FIG. **10**B is a perspective view illustrating a waveguide of the touch panel according to the second exemplary embodiment of the present inventive concept in an unfolded state. FIG. **10**C is a schematic top plan view illustrating the touch panel according to the second exemplary embodiment of the present inventive concept in an unfolded state. FIGS. **11**A to **11**C are schematic diagrams illustrating methods of obtaining touch coordinate values by the touch device according to the second exemplary embodiment of the present inventive concept. FIG. **12** is a flowchart of a touch detecting method of the touch device according to the second exemplary embodiment of the present inventive concept.

Referring to FIG. **9**, a display device **20** according to the second exemplary embodiment of the present inventive concept may include a touch device, a display panel **940**, and an application processor **950**. The touch device may include a waveguide **901**, a filler **902**, a touch panel **900** including inter-digital transducers **911***a* and **911***b* and ultrasonic receiving transducers **912***a* and **912***b*, an ultrasonic transmitter **921**, an ultrasonic receiver **922**, and a touch controller **930**. The touch device according to the second exemplary embodiment of the present inventive concept is not limited to constituent elements shown in FIG. **9**, and may include more or fewer constituent elements than the constituent elements shown in FIG. **9**.

For better understanding and ease of description, although the touch panel **900** of the touch device is show in an unfolded state in FIG. **9**, the touch panel **900** according to the second exemplary embodiment of the present inventive concept is provided as a foldable type to surround a front surface, a back surface, and at least one lateral surface of the display panel **940** as shown in FIG. **10**A.

The waveguide **901** is a medium for an ultrasonic signal to be propagated along an outer surface of the display panel **940**. In order to detect a touch input on the outer surface of the display panel **940** using energy leakage of an ultrasonic signal due to the touch input, it is required that the ultrasonic signal is overall propagated on the outer surface of the display panel **940** at which the touch input needs to be detected. Accordingly, in order to detect a touch input on a plurality of surfaces including the front, back, and at least one lateral surfaces of the display panel **940**, the waveguide **901** propagating the ultrasonic signal needs to be disposed at the front, back, and at least one lateral surfaces of the display panel **940**.

Referring to FIGS. **10**A to **10**C, the waveguide **901** according to the second exemplary embodiment of the present inventive concept is formed in a zigzag form along the front and back surfaces of the display panel **940** and one lateral surface thereof connecting the front and back surfaces to surround the front, back, and one lateral surfaces of the display panel **940**. That is, the waveguide **901** is repeatedly bent and disposed to surround the front, back, and one lateral surfaces of the display panel **940**.

Referring to FIG. **10**C, the waveguide **901** is divided into a front surface portion **1010** disposed to cover the front surface of the display panel **940**, a back surface portion **1020** disposed to cover the back surface of the display panel **940**, and a connecting portion **1030** disposed to cover the one lateral surface of the display panel **940** and connecting the front surface portion **1010** and the back surface portion **1020** The front surface portion **1010** is disposed on the front surface of the display panel **940** and has a predetermined width and interval. The front surface portion **1010** includes a plurality of sub-waveguides **1011** repeatedly disposed to cover the front surface of the display panel **940**. As one portion of the waveguide **901**, the back surface portion **1020** is disposed on the back surface of the display panel **940** and has a predetermined width and interval. The back surface portion **1020** includes a plurality of sub-waveguides **1021** repeatedly disposed to cover the back surface of the display panel **940**. As one portion of the waveguide **901**, the connecting portion **1030** is disposed on the lateral surface of the display panel **940** and has a predetermined width and interval. The connecting portion **1030** includes a plurality of sub-waveguides **1031** connecting the sub-waveguides **1011** of the front surface portion **1010** and the sub-waveguides **1021** of the back surface portion **1020**. The width of the wave guide in the front surface portion **1010**, the back surface portion **1020** and the connecting portion **1030** may be same. The interval of the wave guide in the front surface portion **1010**, the back surface portion **1020** and the connecting portion **1030** may be same.

In the present exemplary embodiment, the waveguide **901** may be formed by combining the front surface portion **1010**, the back surface portion **1020**, and the connecting portion **1030** that are separately formed. That is, the waveguide **901** may be formed by combining the sub-waveguides **1011**, **1021**, and **1031** configuring the front surface portion **1010**, the back surface portion **1020**, and the connecting portion **1030** that are separately formed. On the other hand, the waveguide **901** may be formed in one plate shape, and then may be bent to form the front surface portion **1010**, the back surface portion **1020**, and the connecting portion **1030** in a foldable type.

The waveguide **901** may be formed within 2 mm in width to ensure touch accuracy.

Fillers **902** are filled between the respective sub-waveguides **1011**, **1021**, and **1031** to flatten the outer surface of the touch panel **900**. The filler **902** may be formed of a material of which the acoustic impedance differs from that of the waveguide **901** by more than a predetermined value so that the ultrasonic signal may be propagated within the waveguide **901** through total reflection.

To prevent gaps between the respective sub-waveguides **1011**, **1021**, and **1031** configuring the waveguide **901** from being viewed by a user, the interval between the respective sub-waveguides **1011**, **1021**, and **1031** are formed in a minimum width to the extent that total reflection of the ultrasonic signal propagated within the waveguide **901** is not disturbed. Further, the gaps between the respective sub-waveguides **1011**, **1021**, and **1031** may be aligned in a black matrix (PB), and an index matching material may be used as a filler of the gaps.

The touch panel **900** may include assistant layers **1001** and **1002** that are provided between the outer surfaces (at least one of the front, back, and lateral surfaces) of the waveguide **901** and the display panel **240**. The assistant layers **1001** and **1002** may be formed of a material of which the acoustic impedance differs from that of the waveguide **901** by more than a predetermined value so that the ultrasonic signal may be propagated within the waveguide **901** of the touch panel **900**.

A first inter-digital transducer **911***a* and a first ultrasonic receiving transducer **912***a* are combined to one end of the waveguide **901**. A second inter-digital transducer **911***b* and a second ultrasonic receiving transducer **912***b* are combined to the other end of waveguide **901**.

The first inter-digital transducer **911***a* and the second inter-digital transducer **911***b* respectively generate the ultrasonic signal at different end portions of the waveguide **901**, and the waveguide **901** propagates the generated ultrasonic signal along the front, one lateral, and back surfaces of the display panel **940** to be transmitted to the respective ultrasonic receiving transducers **912***b* and **912***a*.

The ultrasonic signal generated by the first inter-digital transducer **911***a* is propagated along the waveguide **901** to be received by the second ultrasonic receiving transducer **912***b*. The ultrasonic signal generated at the second ultrasonic receiving transducer **912***b* is propagated along the waveguide **901** to be received by the first ultrasonic receiving transducer **912***a*.

A kind of medium forming the waveguide **901** is not limited, but a material of which acoustic impedance differs from that of external air by more than a predetermined value may be used so that loss of ultrasonic signal occurs while an ultrasonic signal is propagated may be prevented.

The waveguide **901** may be formed of a transparent material to prevent a loss of transparency of the display panel **940**.

The waveguide **901** may be formed of glass, plastic, a polymer, or the like.

The first and second inter-digital transducers **911***a* and **911***b* may be actuators that convert an input electrical signal into a vibration signal to generate an ultrasonic signal. The first and second inter-digital transducers **911***a* and **911***b* may respectively include a piezoelectric substrate and an electrode formed on the piezoelectric substrate. The first and second inter-digital transducers **911***a* and **911***b* are respectively combined to different end portions of the waveguide **901**, and generate the ultrasonic signal at different end portions of the waveguide **901**.

Each of the first and second ultrasonic receiving transducers **912***a* and **912***b* is an actuator that receives a vibration signal which is an ultrasonic signal and converts the received vibration signal to an electrical signal. Each of the first and second ultrasonic receiving transducers **912***a* and **912***b* may include a piezoelectric substrate and an electrode formed on the piezoelectric substrate. The first and second ultrasonic receiving transducers **912***a* and **912***b* are respectively combined to different end portions of the waveguide **901**, and generate the ultrasonic signal at different end portions of the waveguide **901**.

Referring back to FIG. **9**, the ultrasonic transmitter **921** is connected with the first and second inter-digital transducers **911***a* and **911***b*. The ultrasonic transmitter **921** supplies driving signals (driving voltages) to the first and second inter-digital transducers **911***a* and **911***b* to generate ultrasonic signals.

The ultrasonic receiver **922** is connected with the first and second ultrasonic receiving transducers **912***a* and **912***b*. The ultrasonic receiver **922** processes electrical signals outputted from the first and second ultrasonic receiving transducers **912***a* and **912***b* to generate touch signals.

A gain of an electrical signal outputted from each of the first and second ultrasonic receiving transducers **912***a* and

912*b* is determined depending on intensity of an ultrasonic signal received at each of the ultrasonic receiving transducers **912***a* and **912***b*. That is, as the intensity of the ultrasonic signal received at the ultrasonic receiving transducer **912***a* and **912***b* is greater, the gain of the electrical signal outputted from the ultrasonic receiving transducers **912***a* and **912***b* increases. Accordingly, the ultrasonic receiver **922** generates a touch signal representing intensity variation of the ultrasonic signal in the ultrasonic receiving transducers **912***a* and **912***b* according to the electrical signal outputted from the ultrasonic receiving transducers **912***a* and **912***b*.

The ultrasonic receiver **922** is connected with the touch controller **930**, and outputs the touch signal to the touch controller **930**.

The touch controller **930** processes the touch signal outputted from the ultrasonic receiver **922**, and outputs a touch event such as a touch coordinate (value) of a touch point to the application processor **950**.

The ultrasonic signal generated at the inter-digital transducers **911***a* and **911***b* is delayed while propagating through the waveguide **901**, and then is transmitted to the ultrasonic receiving transducers **912***b* and **912***a*. While the ultrasonic signal is propagated through the waveguide **901**, a time delay after the energy leakage due to the touch until the ultrasonic signal is transmitted to each of the ultrasonic receiving transducers **912***b* and **912***a* varies depending on a touch position. As the touch point is closer to the ultrasonic receiving transducers **912***a* and **912***b* (or farther to the inter-digital transducers **911***a* and **911***b*), the time for the ultrasonic signal with the energy leakage due to the touch to reach the ultrasonic receiving transducer **912***a* and **912***b* is shortened.

The touch controller **930** obtains a time point at which a signal intensity variation of greater than or equal to a threshold value sufficient to detect the touch event is detected at the first and second ultrasonic receiving transducers **912***a* and **912***b*, based on the touch signal received by the ultrasonic receiver **922**. Further, the touch controller **930** obtains a touch coordinate based on a time difference between the time points at which the signal intensity variation of greater than or equal to the threshold value is respectively detected at the first and second ultrasonic receiving transducers **912***a* and **912***b*.

A detecting method of a touch coordinate performed by the touch controller **930** will now be described in detail with reference to FIGS. **11**A to **11**C. FIGS. **11**A to **11**C illustrate signal intensity variation with respect to time of an ultrasonic signal received by each of the ultrasonic receiving transducers **912***a* and **912***b* according to touch occurrence.

When a touch point is a center of the waveguide **901**, a relational equation between time points a_{t1} and a_{t2} when an ultrasonic signal of which the signal intensity decreases corresponding to the touch point is received by the first ultrasonic receiving transducer **912***a* and the second ultrasonic transducer **912***b*, respectively, is the same as in the following Equation 1.

$$a_{t1}-a_{t2}=0 \quad \text{[Equation 1]}$$

Referring to Equation 1, when the touch point is the center of the waveguide **901**, the ultrasonic signal of which the signal intensity decreases corresponding to the touch point is received by the first ultrasonic receiving transducer **912***a* and the second ultrasonic transducer **912***b* at the same time point.

When the time points a_{t1} and a_{t2} at which the signal intensity variation of greater than or equal to the threshold value due to the touch at the first and second ultrasonic receiving transducers **912***a* and **912***b* is detected are equal, the touch controller **930** determines that the center of the waveguide **901** is touched. Further, the touch controller **930** obtains a coordinate on the display panel **940** corresponding to the center of the waveguide **901** as a touch coordinate.

When the touch point on the waveguide **901** is closer to the first inter-digital transducers **911***a* and the first ultrasonic receiving transducer **912***a* than the center of the waveguide **901**, a relational equation between the time a_{t1} and a_{t2} at which the signal intensity variation of greater than or equal to the threshold value due to the touch at the first ultrasonic receiving transducer **912***a* and the second ultrasonic transducer **912***b* is detected is the same as in the following Equation 2.

$$a_{t1}-a_{t2}>0 \quad \text{[Equation 2]}$$

Referring to Equation 2, when the touch point on the waveguide **901** is closer to the first inter-digital transducers **911***a* and the first ultrasonic receiving transducer **912***a* than the center of the waveguide **901**, the ultrasonic signal of which the signal intensity decreases while passing the touch point is first received by the first ultrasonic receiving transducer **912***a* rather than the second ultrasonic receiving transducer **912***b*.

When the ultrasonic signal is propagated within the waveguide **901** at a constant speed, a distance from the center of the waveguide **901** to the touch point is proportional to the time difference between the time points a_{t1} and a_{t2} at which the signal intensity variation of greater than or equal to the threshold value is detected at the first and second ultrasonic receiving transducers **912***a* and **912***b*, and a propagation speed of the ultrasonic signal within the waveguide **901**.

When the ultrasonic signal of which the signal intensity decreases while passing the touch point is first transmitted to the first ultrasonic receiving transducer **912***a* rather than the second ultrasonic transducer **912***b*, the touch controller **930** determines that the touch point is closer to the first inter-digital transducer **911***a* and the first ultrasonic receiving transducer **912***a* than the center of the waveguide **901**. In addition, the touch controller **930** obtains a position of the touch point on the waveguide **901** through the following Equation 3.

$$\text{Touch point position} = \text{center position} - \left[\frac{(a_{t1}-a_{t2})}{2}\right] \times \text{propagation speed} \quad \text{[Equation 3]}$$

Herein, the center position stands for the center of the waveguide **901**, and the propagation speed stands for the propagation speed of the ultrasonic signal within the waveguide **901**. Further, the touch point position stands for the position of the touch point within the waveguide **901**.

When a touch point position is calculated through Equation 3, the touch controller **930** converts the calculated touch point position into a coordinate on the display panel **940**, and obtains the converted coordinate as a touch coordinate. A specific point at the waveguide **901** is positioned at a specific point on the display panel **940**. The touch controller **930** converts the touch point position calculated through Equation 3 into the coordinate on the display panel **940** based on a correspondence relationship between each point of the waveguide **901** and each point of the display panel **940**.

When the touch point on the waveguide **901** is closer to the second inter-digital transducer **911***b* and the second ultrasonic receiving transducer **912***b* than the center of the waveguide **901**, a relational equation between the time a_{t1} and a_{t2} at which the signal intensity variation of greater than or equal to the threshold value due to the touch at the first ultrasonic receiving transducer **912***a* and the second ultrasonic transducer **912***b* is detected is the same as in the following Equation 4.

$$a_{t1}-a_{t2}<0 \qquad \text{[Equation 4]}$$

Referring to Equation 4, when the touch point on the waveguide **901** is closer to the second inter-digital transducer **911***b* and the second ultrasonic receiving transducer **912***b* than the center of the waveguide **901**, the ultrasonic signal of which the signal intensity decreases while passing the touch point is first received by the second ultrasonic transducer **912***b* rather than the first ultrasonic receiving transducer **912***a*.

When the ultrasonic signal of which the signal intensity decreases while passing the touch point is first transmitted to the second ultrasonic receiving transducer **912***b* rather than the first ultrasonic transducer **912***a*, the touch controller **930** determines that the touch point is closer to the second inter-digital transducer **911***b* and the second ultrasonic receiving transducer **912***b* than the center of the waveguide **901**. In addition, the touch controller **930** obtains a position of the touch point on the waveguide **901** through the following Equation 5.

$$\text{Touch point position} = \text{center position} + \left[\frac{(a_{t2}-a_{t1})}{2}\right] \times \text{propagation speed} \qquad \text{[Equation 5]}$$

When a touch point position is calculated through Equation 5, the touch controller **930** converts the calculated touch point position into a coordinate on the display panel **940**, and obtains the converted coordinate as a touch coordinate. A specific point at the waveguide **901** corresponds to a specific point on the display panel **940**. The touch controller **930** converts the touch point position calculated through Equation 5 into the coordinate on the display panel **940** based on a correspondence relationship between each point of the waveguide **901** and each point of the display panel **940**.

FIG. **11**A illustrates respective signal intensity variations according to time of ultrasonic signals **1101** and **1102** respectively received to a first ultrasonic receiving transducer **912***a* and a second ultrasonic transducer **912***b* when one point TP**111** of the waveguide **901** is touched.

Referring to FIG. **11**A, while an ultrasonic signal transmitted from the first inter-digital transducer **911***a* is propagated along the waveguide **901** and is transmitted to the second ultrasonic receiving transducer **912***b*, energy of the ultrasonic signal is lost when passing the touch point TP**111**. Further, while an ultrasonic signal transmitted from the second inter-digital transducer **911***b* is propagated along the waveguide **901** and is transmitted to the first ultrasonic receiving transducer **912***a*, energy of the ultrasonic signal is lost when passing the touch point TP**111**.

As shown in FIG. **11**A, when the point TP**111** that is closer to the first inter-digital transducer **911***a* than a center of the waveguide **901** is touched, the ultrasonic signal of which the energy is lost by the touch point TP**111** is first transmitted to the first ultrasonic receiving transducer **912***a* rather than the second ultrasonic receiving transducer **912***b*. In this case, the touch controller **930** may obtain a position of the touch point TP**111** through Equation 3 described above.

FIG. **11**B illustrates respective signal intensity variations according to time of ultrasonic signals **1111** and **1112** respectively received by the first ultrasonic receiving transducer **912***a* and the second ultrasonic transducer **912***b* when two points on the waveguide **901** are multi-touched.

Referring to FIG. **11**B, while an ultrasonic signal transmitted from the first inter-digital transducer **911***a* is propagated along the waveguide **901** and is transmitted to the second ultrasonic receiving transducer **912***b*, energy of the ultrasonic signal is lost while passing two touch points TP**121** and TP**122**. Further, while an ultrasonic signal transmitted from the second inter-digital transducer **911***b* is propagated along the waveguide **901** and is transmitted to the first ultrasonic receiving transducer **912***a*, energy of the ultrasonic signal is lost while passing the two touch points TP**121** and TP**122**. Accordingly, the signal intensity variation of greater than or equal to the threshold value due to the two touch points TP**121** and TP**122** is detected twice with a time difference at the first and second ultrasonic receiving transducers **912***a* and **912***b*.

FIG. **11**C illustrates respective signal intensity variations according to time of ultrasonic signals **1121** and **1122** respectively received by the first ultrasonic receiving transducer **912***a* and the second ultrasonic transducer **912***b* when three points on the waveguide **901** are multi-touched.

Referring to FIG. **11**C, while an ultrasonic signal transmitted from the first inter-digital transducer **911***a* is propagated along the waveguide **901** and is transmitted to the second ultrasonic receiving transducer **912***b*, energy of the ultrasonic signal is lost while passing three touch points TP**131**, TP**132**, and TP**133**. Further, while an ultrasonic signal transmitted from the second inter-digital transducer **911***b* is propagated along the waveguide **901** and is transmitted to the first ultrasonic receiving transducer **912***a*, energy of the ultrasonic signal is lost while passing the three touch points TP**131**, TP**132**, and TP**133**. Accordingly, the signal intensity variation of greater than or equal to the threshold value due to the three touch points TP**131**, TP**132**, and TP**133** is detected three times with a time difference at the first and second ultrasonic receiving transducers **912***a* and **912***b*.

As shown in FIGS. **11**B and **11**C, when a plurality of points of the waveguide **901** are simultaneously touched, signal intensity variations of greater than or equal to a threshold value are detected corresponding to the number of touch points for a predetermined time (e.g., at least one frame) at the ultrasonic receiving transducers **912***a* and **912***b*.

The touch controller **930** obtains the number of detected signal intensity variations of greater than or equal to the threshold value for the predetermined time based on the touch signal at the first and second ultrasonic receiving transducers **912***a* and **912***b*, and obtains the number of touch points based on the number of detected signal intensity variations. Further, the touch controller **930** obtains a touch order of the respective touch points from time points at which the signal intensity variations are detected.

In case of a plurality of touch points, the touch controller **930** separately obtains time differences (a_{t12}, b_{t12}, and c_{t12}) between time points (a_{t1}, b_{t1}, c_{t1}, a_{t2}, b_{t2}, and c_{t2}) at which the signal intensity variations of greater than or equal to the threshold value are detected corresponding to respective touch points based on the touch signals at the first and second ultrasonic receiving transducers **912***a* and **912***b*.

Further, the touch controller **930** separately calculates positions of the respective touch points by assigning the obtained time differences to Equations 3 and 5.

While an ultrasonic signal generated at each of the inter-digital transducers **911***a* and **911***b* is propagated even in a state without a touch, since energy thereof is lost, a predetermined signal intensity variation (decrease) occurs. Since energy loss of the ultrasonic signal by the waveguide itself **901** may be combined with energy loss by the touch, a false recognition of a touch may occur.

The touch controller **930** may obtain an energy loss amount of the ultrasonic signal by the waveguide itself **901**, that is, a signal intensity variation amount through calibration of the touch device. In addition, by compensating a signal intensity variation amount according to a touch position with the energy loss amount of the ultrasonic signal by the waveguide itself **901** obtained in the calibration, while the touch position is calculated, the touch point calculating error due to combining of the signal intensity variation by the waveguide itself **901** and the signal intensity variation by the touch point may be prevented.

Referring back to FIG. **9**, the touch controller **930** outputs a touch event including a touch coordinate to the application processor **950**.

When the application processor **950** receives the touch event from the touch controller **930**, the application processor **950** processes the touch event. Application software operated in the application processor **950** renders image data (or image frame) for displaying on the display panel **940** according to processing of the touch event received from the touch controller **930**.

The image data rendered by the application processor **950** are transmitted to the display panel **940** and displayed by the display panel **940**.

The display panel **940** displays the image data rendered by the application processor **950**.

The display panel **940** may be a transparent display panel. The transparent display panel maintains transparency with which an object positioned at a rear side of the display panel **940** is able to be viewed at the front of the display panel **940** while the transparent display panel does not display an image. Further, while the transparent display panel displays an image, the transparent display panel maintains predetermined transparency.

The display panel **940** may be realized as various types such as a liquid crystal display (LCD) panel, a thin film transistor liquid crystal display (TFT-LCD) panel, a field emission display (FED) panel, an organic light emitting diode display (OLED) panel, a quantum dot display panel, and the like.

The aforementioned display device **20** is disposed for the waveguide **901** to surround the front, back, and one lateral surface of the display panel **940**, and the touch signal is detected based on the signal intensity variation of the ultrasonic signal propagated through the waveguide **901**. Accordingly, it is possible to detect a touch input on the lateral surface of the display panel **940** as well as on the front and back surfaces of the display panel **940**.

FIG. **12** is a flowchart of a touch detecting method of the touch device according to the second exemplary embodiment of the present inventive concept.

Referring to FIG. **12**, the touch device according to the second exemplary embodiment of the present inventive concept performs calibration (S**900**).

In the calibration step (S**900**), the respective inter-digital transducers **911***a* and **911***b* generate an ultrasonic signal in a state in which no touch occurs. Further, the respective ultrasonic receiving transducers **912***a* and **912***b* receive an ultrasonic signal propagated through the waveguide **901** of the touch device. A difference between intensity of a transmitting ultrasonic signal in the inter-digital transducers **911***a* and **911***b* and intensity of an receiving ultrasonic signal in the ultrasonic receiving transducers **912***a* and **912***b* corresponds to a signal intensity variation (signal intensity decrease) by the waveguide **901**. The touch controller **930** obtains the signal intensity variation by the waveguide **901** based on the difference between intensity of the transmitting ultrasonic signal in the inter-digital transducers **911***a* and **911***b* and the intensity of the receiving ultrasonic signal in the ultrasonic receiving transducers **912***a* and **912***b*. The signal intensity variation by the waveguide **901** may be used to compensate an ultrasonic signal received by the ultrasonic receiving transducers **912***a* and **912***b*.

The touch controller **930** analyzes a touch signal transmitted from the ultrasonic receiver **922**, and at which a signal intensity variation of greater than or equal to a threshold value from an ultrasonic signal received by the respective ultrasonic receiving transducers **912***a* and **912***b* is detected, the touch controller **930** recognizes that a touch occurs (S**910**).

When touch detection is started, the respective inter-digital transducers **911***a* and **911***b* continuously (or periodically) generate an ultrasonic signal. Further, the respective ultrasonic receiving transducers **912***a* and **912***b* continuously (or periodically) receive an ultrasonic signal propagated through the waveguide **901** of the touch device. The ultrasonic signal received through the respective ultrasonic receiving transducers **912** is converted into a touch signal representing a signal intensity variation according time in the respective ultrasonic receiving transducers **912***a* and **912***b* by the ultrasonic receiver **922**, and is transmitted to the touch controller **930**.

When a touch is recognized, the touch controller **930** obtains, through the touch signal, time points a_{t1} and a_{t2} at which a signal intensity variation of greater than or equal to a threshold value is detected in an ultrasonic signal received by the first and second ultrasonic receiving transducers **912***a* and **912***b*.

When the time points a_{t1} and a_{t2} at which the signal intensity variation of greater than or equal to the threshold value is detected in the ultrasonic signal received by the first and second ultrasonic receiving transducers **912***a* and **912***b* are equal (S**920**), the touch controller **930** determines that a center of the waveguide **901** is touched. Accordingly, the center position of the waveguide **901** is recognized as a touch point (S**930**).

When the time point a_{t1} at which the signal intensity variation of greater than or equal to the threshold value is detected in the first ultrasonic receiving transducer **912***a* is greater than the time point a_{t2} at which the signal intensity variation of greater than or equal to the threshold value is detected in the second ultrasonic receiving transducer **912***b*, that is, $(a_{t1}-a_{t2}>0)$ (S**940**), the touch controller **930** calculates a position of the touch point through Equation 3 described above (S**950**).

On the contrary, when the time point a_{t1} at which the signal intensity variation of greater than or equal to the threshold value is detected in the first ultrasonic receiving transducer **912***a* is smaller than the time point a_{t2} at which the signal intensity variation of greater than or equal to the threshold value is detected in the second ultrasonic receiving transducer **912***b*, that is, $(a_{t1}-a_{t2}<0)$ (S**940**), the touch controller **930** calculates a position of the touch point through Equation 5 described above (S**960**).

When the touch controller **930** recognizes that a plurality of points are touched by multiple touches at step S**910**, steps S**920** to S**960** are performed with respect to the respective touch points to obtain a position of the respective touch points.

When the touch controller **930** obtains the positions of the respective touch points by performing steps S**920** to S**960**, the touch controller **930** generates touch events including the obtained positions of the respective touch points (S**970**).

According to the aforementioned exemplary embodiments of the present inventive concept, in the touch device, the waveguide is disposed to cover the front, back, and at least one lateral surface of the display panel, and touch coordinates of the touch points in the front, back, and at least one lateral surface of the display panel may be obtained based on the signal intensity variation of the ultrasonic signal propagated through the waveguide display panel.

A method for providing a user interface (UI) to a display device provided with a touch device that is designed to enable a multiple surface touch according to the exemplary embodiments of the present inventive concept will now be described.

FIGS. **13** to **18** illustrate methods for providing user interfaces to the display devices according to the exemplary embodiments of the present inventive concept.

FIG. **13** illustrates an example of scrolling a display surface through a lateral touch input in the display device according to the exemplary embodiments of the present inventive concept.

When one lateral surface covered by the touch panel (see reference numeral **200** of FIG. **2** and reference numeral **900** of FIG. **9**) of the display device **20** is touched and dragged by a user's finger, the display device **20** according to the exemplary embodiments of the present inventive concept scrolls a display surface of the display device **20** in a direction corresponding to the dragging direction.

Referring to FIG. **13**, as a lateral surface **23** covered by the touch panels **200** and **900** is dragged (TI**13**) by the user's finger F, the display device **20** scrolls an object OB**13** that is being displayed on the display surface down and displays the down-scrolled object down.

When the one lateral surface covering the touch panels **200** and **900** of the display device **20** is touched and dragged by the user's finger F, the display device **20** may update and display information (or an object) that is being displayed on the display surface in a frame unit or an object unit depending on the dragging direction. For example, when an object being displayed on the display surface is a photograph, as the lateral surface **23** covered by the touch panels **200** and **900** is dragged (TI**13**) by the user's finger F, the display device **20** may display a next photograph or a previous photograph on the display surface corresponding to the dragging direction.

As described above, the display device **20** according to the exemplary embodiments of the present inventive concept may drag a lateral surface, and may scroll or update information (or an object) that is being displayed on the display surface depending on the dragging of the lateral surface. Accordingly, a user may input a touch gesture for scrolling or updating information (or an object) that is presently displayed on the display without covering the information (or object) presently displayed on the display with a hand.

FIGS. **14** to **15**B illustrate examples of providing a user interface for touch inputs on both surfaces in the display device according to the exemplary embodiments of the present inventive concept.

The display device **20** according to the exemplary embodiments of the present inventive concept, since the front and back surfaces of the display device **20** are covered by the touch panels **200** and **900**, may recognize a user's multiple touch inputs on the front and back surfaces of the display device **20**.

Referring to FIG. **14**, the display device **20** receives touch inputs TI**14** dragged in opposite directions to each other in a multiple touch state in which the front surface **21** and the back surface **22** are simultaneously touched by two fingers F**1** and F**2**. That is, the display device **20** receives the touch input TI**14** for which one F**1** of the two fingers that touch the front surface **21** and the back surface **22** is dragged in a upper direction (or a lower direction) and the other F**2** is dragged in the lower direction (or the upper direction). Accordingly, the display device **20** may rotate and display an object OB**14** presently displayed on the display surface in a corresponding direction. As described above, the display device **20** according to the exemplary embodiments of the present inventive concept may provide the user with an intuitive user interface by rotating the object presently displayed on the display surface by the touch gesture (drag) like holding and rotating an actual object in the state in which the both surfaces (the front surface and the back surface) are multi-touched.

Referring to FIG. **15**A, the display device **20** receives touch inputs TI**151** in which two fingers F**1** and F**2** are dragged in a specific direction (e.g., an inner direction of the display surface or a left direction) in a multiple touch state in which the front surface **21** and the back surface **22** are simultaneously touched by the two fingers F**1** and F**2**. Accordingly, the display device **20** may transmit an image being presently displayed on the display surface to an external device (e.g., a printer) presently connected to the display device **20**.

Referring to FIG. **15**B, the display device **20** receives touch inputs TI**152** in which two fingers F**1** and F**2** are dragged in a specific direction (e.g., an outer direction of the display surface or a right direction) in a multiple touch state in which the front surface **21** and the back surface **22** are simultaneously touched by the two fingers F**1** and F**2**, and then scans and store an image being presently displayed on the display surface.

FIGS. **16**A to **18** illustrate examples of providing a user interface for a touch input on a back surface in the display device according to the exemplary embodiments of the present inventive concept.

Referring to FIG. **16**A, the display device **20** receives a touch input TI**161** in which a user's hand H is dragged in a specific direction (e.g., a right direction) in a state that the user's hand H touches over a predetermined area of the back surface. Accordingly, the display device **20** may copy an object OB**16** being presently displayed on the display surface in a clipboard.

Referring to FIG. **16**B, the display device **20** receives a touch input TI**162** that a user's hand H is dragged in a specific direction (e.g., a left direction) in a state that the user's hand H touches over a predetermined area of the back surface. Accordingly, the display device **20** may paste the object OB**16** copied in the clipboard on the display surface.

Referring to FIG. **17**, the display device **20** may execute an erase operation by a user's hand H or finger being dragged and rubbing the back surface **22** more than twice in a state that the user's hand H or finger touches over a predetermined area of the back surface **22**. That is, as the back surface **22** of the display device **20** is dragged in a zigzag direction in a state that the user's hand H or finger touches over a predetermined area of the back surface **22** of the display device **20**, an object OB**17** being presently displayed on the display surface may be erased from the display surface, or some of information (or objects) displayed on the display surface, which corresponds to a touch trace, may be removed from the display surface.

Referring to FIG. **18**, as two fixed points on the back surface **22** are touched by a user's fingers F**1** and F**2** for more than a predetermined period of time, the display device **20** may execute a ruler operation. Accordingly, a ruler for measuring length of an object OB**18** is displayed between the two touch points.

As described above, the display device according to the exemplary embodiments of the present inventive concept may provide various and intuitive user interfaces by supporting touch inputs on the front, back, and at least one lateral surface of the display device.

While this inventive concept has been described in connection with what is presently considered to be practical exemplary embodiments, it is to be understood that the inventive concept is not limited to the disclosed embodiments, but, on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims.

What is claimed is:

1. A touch device comprising:

a first substrate;

a second substrate facing the first substrate, and disposed to be spaced apart from the first substrate;

a third substrate connecting first end portions of the first and second substrates to each other, and propagating an ultrasonic signal propagated along the first substrate to the second substrate;

a plurality of first ultrasonic transducers connected to a second end portion of the first substrate, and propagating an ultrasonic signal to the first substrate; and

a plurality of second ultrasonic transducers connected to a second end portion of the second substrate, and receiving an ultrasonic signal propagated along the second substrate,

wherein a touch point is detected based on signal intensity variations of ultrasonic signals received by the second ultrasonic transducers,

wherein the first, second, and third substrates are disposed to cover a front surface, a back surface, and one lateral surface of a display panel,

wherein a first assistant layer with different acoustic impedance from that of the first substrate is provided between the first substrate and the display panel, and

wherein a second assistant layer with different acoustic impedance from that of the second substrate is provided between the second substrate and the display panel.

2. The touch device of claim **1**, wherein

the first, second, and third substrates are waveguides guiding an ultrasonic signal generated by the first ultrasonic transducer, and have the same acoustic impedance.

3. The touch device of claim **1**, wherein

when one of the first, second, and third substrates is touched, an intensity variation of greater than or equal to a threshold value is detected at least one of the second ultrasonic transducers.

4. The touch device of claim **3**, wherein

a touch coordinate of the touch point is calculated based on a position and the number of the at least one second ultrasonic transducers at which the intensity variation of greater than or equal to the threshold value is detected and a signal intensity variation in the at least one second ultrasonic transducer.

5. The touch device of claim **1**, further comprising

a guide bar disposed between the first ultrasonic transducers in the second end portion of the first substrate, and propagating an ultrasonic signal generated by the first ultrasonic transducers to an overall area of the first substrate.

6. The touch device of claim **5**, further comprising

at least one convex lens disposed between the guide bar and the second end portion of the first substrate, and focusing the ultrasonic signal generated by the first ultrasonic transducers in a thickness direction of the first substrate.

7. The touch device of claim **5**, wherein

at least one convex portion with a convex lens shape focusing the ultrasonic signal generated by the first ultrasonic transducer in the thickness direction of the first substrate is formed at one surface of the guide bar contacting the second end portion of the first substrate.

8. The touch device of claim **1**, further comprising

a fourth substrate connecting third end portions of the first substrate and the second substrate to each other, propagating the ultrasonic signal propagated along the first substrate to the second substrate;

a plurality of third ultrasonic transducers combined with fourth end portion of the first substrate, propagating an ultrasonic signal to the first substrate; and

a plurality of fourth ultrasonic transducers combined with fourth end portion of the second substrate, and receiving the ultrasonic signal propagated along the second substrate.

9. The touch device of claim **8**, wherein

a first coordinate of the touch point is obtained based on a signal intensity variation of the ultrasonic signal received by the second ultrasonic transducers, and

a second coordinate of the touch point is obtained based on a signal intensity variation of the ultrasonic signal received by the fourth ultrasonic transducers.

10. The touch device of claim **9**, wherein

the first coordinate is obtained from a position of the at least one second ultrasonic transducer at which the intensity variation of greater than or equal to the threshold value is detected, and

the second coordinate is obtained from a position of the at least one fourth ultrasonic transducer at which the intensity variation of greater than or equal to the threshold value is detected.

11. The touch device of claim **1**, wherein

the first and second substrates are a substrate, a cover window, or a cover lens of the display panel.

12. The touch device of claim **1**, wherein

the first, second, and third substrates are integrally formed, and bent to surround the front surface, the back surface and at least one side surface of a display panel.

13. A display device, comprising:

a touch device including:

a first substrate,

a second substrate facing the first substrate, and disposed to be spaced apart from the first substrate,

a third substrate connecting first end portions of the first and second substrates to each other, and propagating an ultrasonic signal propagated along the first substrate to the second substrate,

a plurality of first ultrasonic transducers connected to a second end portion of the first substrate, and propagating an ultrasonic signal to the first substrate, and a plurality of second ultrasonic transducers connected to a second end portion of the second substrate, and receiving an ultrasonic signal propagated along the second substrate, wherein a touch point is detected based on signal intensity variations of ultrasonic signals received by the second ultrasonic transducers; and

a display panel,

wherein a front surface, a back surface, and one lateral surface of the display panel are covered by the first, second, and third substrates of the touch device,

wherein a first assistant layer with different acoustic impedance from that of the first substrate is provided between the first substrate and the display panel, and

wherein a second assistant layer with different acoustic impedance from that of the second substrate is provided between the second substrate and the display panel.

14. The display device of claim **13**, wherein

when the third substrate of the touch device is touched and dragged, an object being displayed on the display panel is scrolled.

15. The display device of claim **13**, wherein

when the first substrate and the second substrate of the touch device are simultaneously touched and are dragged in different directions from each other, an object being displayed on the display panel is rotated.

16. The display device of claim **13**, wherein

when the first substrate and the second substrate of the touch device are simultaneously touched and are dragged in a specific direction, an image being displayed on the display panel is transmitted to an external device presently connected to the display device.

17. The display device of claim **13**, wherein

when the first substrate and the second substrate of the touch device are simultaneously touched and are dragged in a specific direction, an image being displayed on the display panel is captured or scanned.

18. The display device of claim **13**, wherein

when the second substrate of the touch device is touched in more than a predetermined area and then dragged in a first direction, an object being displayed on the display panel is copied to a clipboard.

19. The display device of claim **18**, wherein

when the second substrate of the touch device is touched more than a predetermined area and then dragged in a second direction, the object copied in the clipboard is pasted on the display panel.

20. The display device of claim **13**, wherein

when the second substrate of the touch device is touched at more than a predetermined area and dragged in a zigzag direction, at least one part of information being displayed on the display panel is removed.

21. The display device of claim **13**, wherein

when a plurality of points on the second substrate of the touch device are touched for more than a predetermined period of time, a ruler for measuring length is displayed between points.

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